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WAR DEPARTMENT TECHNICAL MANUAL

AVIATION ENGINEERS

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WAR D **ANUAL**

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IC 5 (5): T/O 5-500, Avn Firefighting Platoon.
IC 5 (3): T/O 5-21, Engr Gen Sv Co, 5-185, Engr Topographic Co.
IC 5 (2): T/O 5-15 Engr Combat Co.

For explanation of symbols see FM 21-6.

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Figure 1. Keep 'em flying.

This manual supersedes TM 5-255 (Tentative), 31 December 1942, including Changes No. 1, 13 May 1943.

PART ONE

TROOPS

CHAPTER 1

SCOPE

1. PURPOSE. **a.** This manual covers both tactical and technical phases of the training and operations of aviation engineers with special reference to their employment in theaters of operations. It is designed to be used as a reference handbook as well as a text for training purposes.

b. The technical problems confronting aviation engineer units are so varied they cannot be covered in detail in one text. However *each problem requires careful judgment in the application of sound engineering principles.* This manual is a guide to those principles and to their application.

2. ORGANIZATION OF MANUAL. **a.** The subject matter of the manual falls naturally into two parts. The first part provides a general background of the mission, organization, and training of aviation engineer units. Included is a brief chapter on the operations of airborne aviation engineer units.

b. The second part covers all phases of airdrome construction. So far as possible, it is arranged in a continuous, chronological order of construction operations. For convenient reference each phase is covered in a separate chapter.

c. Detailed technical and reference data are organized into six appendixes in the back of the manual.

3. RELATED PUBLICATIONS. **a.** Certain subjects relating to airdrome construction which are not treated in detail in this manual are covered in other manuals. Pioneer construction methods and the uses of hand tools are given in FM 5–10, TM 5–225, and TM 5–226. TM 5–280 and 5–281 cover construction of housing and utilities. Camouflage is covered fully in FM 5–20 and TM 5–266, 5–267, and 5–269.

b. Appendix VI lists reference material and publications particularly useful in operations of aviation engineers. A complete list of training publications is given in FM 21–6.

CHAPTER 2

MISSION

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4. GENERAL. Aviation engineer units are organized to meet the needs of the Army Air Forces for engineer work in theaters of operations. Their work consists primarily of constructing, maintaining, defending, and camouflaging airdromes. Construction tasks vary from advanced landing fields hastily cleared by airborne aviation engineers to large base airdromes constructed in rear areas. However, in every case emphasis is placed on speedy construction.

5. DUTIES IN AIRDROME CONSTRUCTION. Primary duties include the following (for definitions of terms see ch. 7):

a. Landing strips. Construction of landing strips with necessary runways, taxiways, and hard standings, including placing of steel runways.

b. Ground installations. (1) Construction of facilities for refueling and arming aircraft; for storing gasoline supplies, ordnance supplies, and air force supplies; for housing personnel and equipment; and for repairing and maintaining air force equipment.

(2) Construction and operation of utilities for water supply, light, heat, and power.

c. Communications. (1) Construction of service roads within the airdrome and of access roads adjacent to it.

(2) Construction of railroad facilities within the airdrome.

d. Airdrome defense. (1) Local security of own troops.

(2) Assistance in local airdrome defense against air or ground attack.

(3) Construction of weapons emplacements.

(4) Provision of protective structures for personnel and facilities.

(5) Obstacle construction, including laying antitank mines.

(6) Preparation and execution of demolitions to prevent enemy seizure of airdrome facilities.

e. Camouflage. Dispersion and concealment of ground installations, concealment of aircraft on the ground, and construction of decoys. Also camouflage instruction, technical advice, supply of camouflage materials, and assistance to air force personnel.

6. MAINTENANCE, REPAIR, AND STAGE IMPROVEMENT. Aviation engineer units are responsible for maintenance and repair of the facilities and utilities which they construct. By stage construction they improve initial facilities to the required stage of development.

7. REHABILITATION OF CAPTURED AIRDROMES. The rehabilitation of captured airdromes is a responsibility of aviation engineer units. In a theater in which our forces are advancing the majority of our supporting aircraft may operate from these airdromes. In rehabilitating them aviation engineer units must be prepared to remove booby traps and land mines prior to construction operations.

8. OTHER DUTIES. Other duties include—

a. Establishment and operation of engineer supply.

b. Operation of fire-fighting detachments.

c. Mapping and map reproduction, including assistance in field preparation and reproduction of aeronautical charts such as navigation charts, approach charts, and target maps.

9. OTHER ENGINEER UNITS. Combat engineer battalions and general service regiments occasionally may be assigned to airdrome construction tasks. (See par. 27.)

CHAPTER 3

ORGANIZATION AND DUTIES

10. GENERAL. **a.** Aviation engineer units are organized along the same lines as general engineer units. They are assigned to air forces as required.

b. Organization of aviation engineer units is subject to changes arising from new developments. Different theaters of operations may require special organizational features, particularly with respect to staff functions. However, the organization and functions of individual units remain relatively constant.

c. This chapter is a general guide only. It is based on Tables of Organization as of 1 December 1943.

11. AIR FORCE ORGANIZATION IN TYPICAL THEATER OF OPERATIONS. Air force organization is extremely flexible and is determined by the requirements of the theater. A typical organization is shown in figure 2.

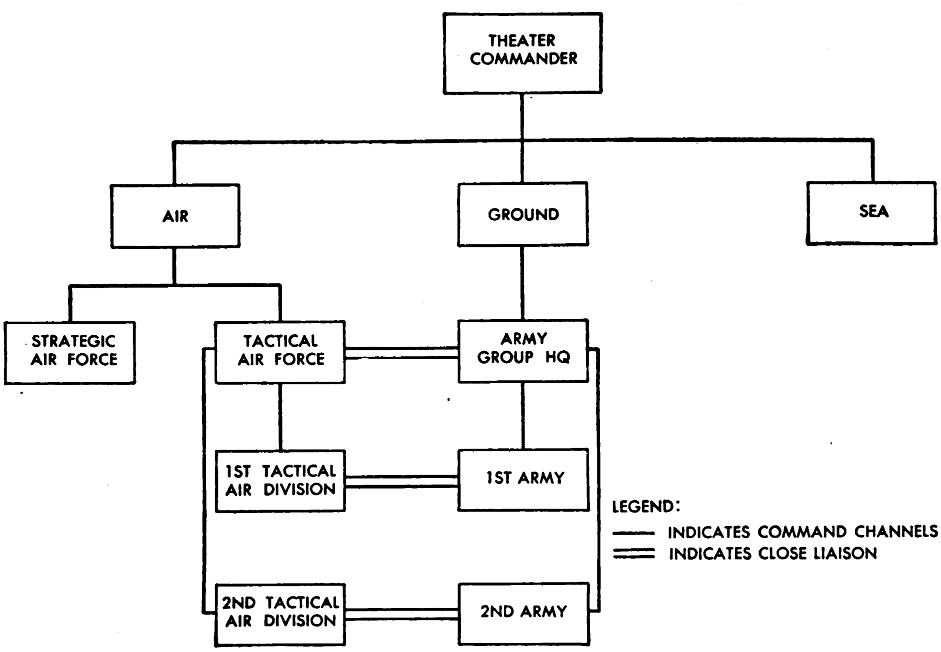

Figure 2. Air force organization in a typical theater of operations.

a. The *strategic air force* is a long-range striking force. It attacks the enemy's industries, communications, and rear-area airdromes. Generally it is composed of heavy and medium bombers and long-range fighters.

b. The *tactical air force* assists in operations of ground forces through close coordination by neutralizing enemy aircraft and airdromes, by intercepting movements of enemy troops and supplies, and by attacking battlefield targets. It is composed of many varied types of aircraft from fighters to medium bombers.

c. Other air force groups, such as a troop carrier command, may be set up for special purposes.

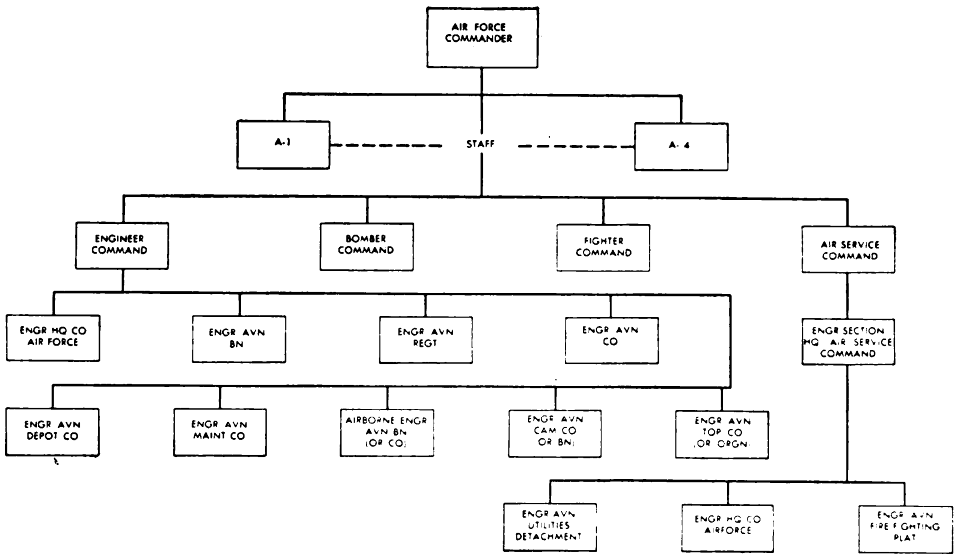

Figure 3. Engineer organization in a typical theater air force.

12. ENGINEER ORGANIZATION IN TYPICAL THEATER AIR FORCE.

a. Engineer organization in a typical theater air force is shown in figure 3. This organization applies to an active theater in which our forces are advancing into enemy territory. The bulk of the construction troops are concentrated under the *engineer command.* Under the *air service command* are those troops needed to maintain and service operating airdromes.

b. Aviation engineer units in an air force may include the following:

(1) Headquarters, engineer command (provisional Table of Organization only).

(2) Engineer section, headquarters, air force (T/O 5–800–1), which is organized only if engineer command does not exist.

(3) Engineer section, headquarters, air service command (T/O&E 1–400–1S).

(4) Engineer air force headquarters company (T/O & E 5–800–2).

(5) Engineer aviation regiment (T/O 5–411).

(6) Engineer aviation battalion (T/O 5–415).

(7) Engineer aviation company (T/O 5–417).
(8) Engineer aviation camouflage battalion (T/O & E 5–465).
(9) Engineer aviation topographic company (T/O 5–447).
(10) Engineer aviation topographic organization (T/O & E 5–400).
(11) Engineer aviation depot company (T/O & E 5–47).
(12) Engineer aviation fire fighting platoon (T/O & E 5–500).
(13) Engineer aviation maintenance company (T/O & E 5–157).
(14) Engineer aviation utilities detachment (T/O 5–500).
(15) Airborne engineer aviation battalion (T/O & E 5–455).
(16) Airborne engineer aviation company (T/O & E 5–457).

13. STAFF FUNCTIONS. **a.** Engineer staff functions depend upon the general engineer organization within the air force. The following discussion is based on an organization similar to that shown in figure 3.

b. The main engineer staff group is the staff of the commanding officer of the engineer command, who is designated as the air force engineer and is concerned primarily with the site selection and construction of new airdromes. As mentioned in paragraph 12, the majority of engineer troops within the air force are placed under this command. In an air force in which a separate engineer command is not organized the staff of the air force engineer is known as the *engineer section, headquarters, air force.* This section operates with other air force staff troops directly under the air force commander.

c. Engineer operations which pertain to maintaining and servicing airdromes that are in operation are supervised by the engineer of the air service command. In a static situation all construction activities and the troops to execute them may be placed under the air service command.

d. Additional engineer staffs may be assigned to fighter and bomber commands and to other commands within the air force. These staffs are relatively small and seldom control construction troops.

14. DETAILED DUTIES OF HEADQUARTERS, ENGINEER COMMAND. **a.** The air force engineer and his staff estimate engineer requirements of the air force and recommend assignment and employment of all its engineer troops. The air force engineer also commands all engineer units not assigned to subordinate commands.

b. Staff duties of the air force engineer include—

(1) Furnishing technical advice and assistance on engineer matters to air force commander.

(2) Planning and supervising employment of all aviation engineer units assigned to air force.

(3) Making reconnaissance and recommendations in conjunction with A–3 as to selection of sites for advanced airdromes.

(4) Preparing air force engineer administrative plans, instructions, orders, and training directives.

(5) Maintaining liaison with engineers of ground forces and service forces.
(6) Determining engineer equipment and material requirements for contemplated air force operations.
(7) Administering engineer funds for air force and supply credits for engineer material.
(8) Inspecting of engineer troops, equipment, and material.

c. Duties of the air force engineer exercised through units under his command include—
(1) Command of all engineer troops not assigned to subordinate units.
(2) Construction of field airdromes and advanced landing fields.
(3) Rehabilitation of captured airdromes through employment of aviation battalions or airborne aviation battalions.
(4) Reproduction of maps, charts, and overlays and, in conjunction with photographic companies, preparation of appropriate charts and target maps as required.

15. DETAILED DUTIES OF ENGINEER SECTION, HEADQUARTERS, AIR SERVICE COMMAND. The engineer, air service command, is responsible for the expansion and maintenance of existing airdromes or air bases occupied by the air force. Duties of the engineer and his staff include—

a. Supervision of engineer activities in the air service command including—
(1) Command of aviation engineer troops not assigned to subordinate units.
(2) Disposition of engineer troops assigned to air service command in accordance with approved plans.
(3) Establishment and operation, as necessary, of engineer supply points for camouflage and construction materials.
(4) Procurement, storage, and distribution of engineer supplies and equipment, and collection and salvage of damaged engineer equipment.

b. Maintenance and improvement of air force facilities including—
(1) Maintenance and repair of existing airdromes.
(2) Maintenance and repair of routes of communication to and from airdromes.
(3) Repair of airdromes after enemy bombardment.
(4) Assistance in preparation of plans for defense of existing airdromes against air and ground attack.
(5) Preparation of plans for demolition of existing airdromes.
(6) Construction of mine fields, road blocks, and obstacles.
(7) Maintenance of structures, water supply, and electrical installations.

16. ENGINEER AIR FORCE HEADQUARTERS COMPANY, AIR FORCE. This company is attached to headquarters of the engineer command and operates in close coordination with the headquarters staff. It performs necessary drafting, designing, surveying, planning, and reproduction, and furnishes camouflage assistance in connection with the activities of the construction troops under the air force engineer. Where necessary, an engineer headquarters company may be assigned to the air service command.

17. ENGINEER AVIATION BATTALION. **a.** This battalion is the basic construction unit of the aviation engineers. It is organized and equipped to construct airdromes rapidly. It consists of a battalion headquarters, headquarters and service company, three lettered companies, a medical section and a chaplain.

b. Each lettered company has considerable earth-moving equipment which is supplemented by equipment from headquarters and service company. Lettered companies may be detached from the battalion and used independently for airdrome construction projects, particularly in the preparation of landing strips for advanced landing fields. However, the battalion is the normal field operating unit and is a balanced organization capable of working simultaneously on all phases of construction of an airdrome. In certain situations the battalion organization may be broken up to provide special types of working parties. An example of special organizations is given in paragraph 28, which illustrates the use of forward and rear echelons in a mobile situation. It should be emphasized that the battalion organization is flexible so that the proper equipment can be used for each task.

18. ENGINEER AVIATION REGIMENT. **a.** The engineer aviation regiment is composed of a headquarters, headquarters and service company, and a varying number of battalions. The battalions within the regiment are identical with the battalion described in paragraph 17.

b. The regiment has the same general mission as the battalion but is designed for operations in a large theater where many airdromes are to be constructed in a small area. The employment of a regiment permits decentralization of construction control from the air force engineer. The number of assigned battalions depends upon the area and scope of operations.

c. The regiment may also act as a depot or pool for heavy construction equipment which is issued to other units for special tasks.

19. ENGINEER AVIATION COMPANY. Separate companies have the same general mission as the battalion. They are organized as required for particular missions. They are identical with the lettered company of the battalion except they may have additional construction equipment.

20. ENGINEER AVIATION CAMOUFLAGE BATTALION. In a theater of operations this unit furnishes technical assistance, construction assistance, supervision, and control of the camouflage activities of all air force units in connection with the design, planning, and execution of their camouflage works. It fabricates and supplies camouflage materials from local sources and carries on experimentation for new camouflage methods. The battalion is responsible for the indoctrination and training of all air force units in connection with camouflage policy, discipline, practices, and techniques. It accomplishes these responsibilities by means of schools and field demonstrations and by preparation and dissemination of publications and posters.

21. ENGINEER AVIATION TOPOGRAPHIC COMPANY AND ORGANIZATION. The topographic organization is a unit of varying size, composed of one or more companies depending upon air force requirements. Topographic units work in conjunction with photo reconnaissance units of the air forces. Their general mission is the preparation, compilation, and reproduction of all necessary maps and target charts. Detailed duties include—

a. Compilation, reproduction, and distribution of mosaics and other special map information requested by air force.

b. Plotting, indexing, and storing of film taken by photo reconnaissance aviation. Preparation of special contact prints, enlargements, and restitution of prints from this film.

c. Supplementing ground force facilities in mapping and model-making as directed by the theater commander.

22. ENGINEER AVIATION DEPOT COMPANY. This company handles the storage and distribution of *engineer* equipment, supplies, and construction materials. Issues are based on credits established by the air force engineer.

23. ENGINEER AVIATION FIRE FIGHTING PLATOON. This organization is organized and equipped to fight structural and aircraft fires. It performs rescue operations for both personnel and equipment. For details on fire fighting procedure see TM 5–315 and TM 5–316 (when published).

24. ENGINEER AVIATION MAINTENANCE COMPANY. This company handles third-echelon repair work for engineer equipment.

25. ENGINEER AVIATION UTILITIES DETACHMENT. This detachment is a flexible organization composed of a number of sections of specialists in all phases of airdrome maintenance and operation of utilities. The number and size of sections in a detachment varies according to the requirements of the airdrome to which it is assigned. It is employed in rear areas to release construction units for operations in forward areas. Generally the detachment operates under the engineer section of the air service command.

26. AIRBORNE ENGINEER AVIATION BATTALION COMPANY. These units are organized similarly to the basic battalion and company construction units, except they have lighter *organic* equipment and fewer personnel. Their chief mission is the construction or rehabilitation of airdromes in advanced areas which are not accessible by movement of standard equipment over land or water. Airborne aviation engineers are covered in chapter 5.

27. UNITS OTHER THAN AVIATION ENGINEERS. In special situations general service regiments and combat battalions may be assigned to airdrome construction. Their equipment is not suitable for heavy earth moving unless it is considerably supplemented from depots and equipment companies. Combat units in particular are limited to such projects as access roads, advanced landing fields, and maintenance and rehabilitation work.

28. ORGANIZATION OF AVIATION ENGINEER UNITS FOR CONSTRUCTION. **a.** The battalion is the basic construction unit. The major part of all planning and staff work in an air force is directed towards making maximum use of the heavy construction equipment of the battalions within the air force. Although the battalion and its lettered companies are integral construction units, for any particular task or series of tasks these integral units may be reorganized or expanded instead of being held rigidly to their Tables of Organization.

b. The Table of Organization assignment of equipment within the battalion places a certain amount of heavy equipment in each lettered company. Additional heavy equipment is pooled in headquarters and service company. The battalion may organize for construction in any one or more of the following ways:

(1) Entire battalion acting as a unit under control of the battalion commander. Each company operates its own equipment under S–3 control.

(2) One or more companies may work on separate construction projects at some distance from battalion headquarters. In this case it is desirable to attach to the lettered companies additional equipment and operators from headquarters and service company.

(3) The battalion may be organized in several echelons according to the mobility of the equipment. The forward echelon consists of mobile equipment which accomplishes rough grading and rehabilitation work for advanced landing fields. The rear echelon consists of the heavier and less mobile equipment and of administrative and maintenance sections.

c. During a rapid advance into a hostile territory an organization similar to that described in b (3) above may be desirable. The main object of such organization is to get equipment to the best airdrome sites with as little delay as possible. An example of this organization is as follows:

(1) Reconnaissance parties operate well forward with advance ground force elements. By aerial and ground reconnaissance they select suitable sites. They transmit their information as rapidly as possible to—

(2) An advanced engineer headquarters which assigns the construction tasks to—

(3) Mobile parties, which rapidly clear and grade the sites to make them operational. When a field is completed they leave a small maintenance detail behind and push forward to the next site. Following the mobile parties is a—

(4) Support and maintenance echelon, with heavy equipment necessary to improve the fields placed in operation by the mobile parties. Not all the fields constructed by the mobile parties will be kept in operation. Some of them will be abandoned as the front-line elements advance. Others will be developed into bomber and long-range fighter airdromes.

CHAPTER 4

SCOPE OF TRAINING

29. GENERAL. a. The objective of all aviation engineer training is to prepare units to perform the duties listed in chapters 2 and 3. Particular emphasis is placed on the following:

(1) Development of efficient construction crews.

(2) Full use of combat strength of engineer units in defense of airdromes.

(3) Maintenance of equipment.

b. During the training period aviation engineers are stationed at an airdrome where close contact with other air force personnel, equipment, facilities, and installations is a part of their daily life. *Aviation engineers must be airminded.*

30. CONTROL OF TRAINING. a. All organizations are trained in accordance with existing training directives and Mobilization Training Programs (MTP). The following directives and Mobilization Training Programs apply to aviation engineer units:

(1) Army Air Force Standard 40–8–1. This is the basic training guide for all aviation engineer units. It covers the standards to be achieved by these units.

(2) MTP 5–1. This program applies to all engineer units. It covers both the *basic* and the *technical and tactical* period of training of the individual soldier and lasts for approximately 13 weeks.

(3) MTP 5–5. This program applies to aviation engineer units only. It follows MTP 5–1 and is approximately 11 weeks long. MTP 5–5 covers the *unit* training period, during which individuals learn to work as part of a coordinated team.

b. Aviation engineer units normally are trained under centralized control at engineer aviation unit training centers (EAUTC). EAUTC's prepare programs and supervise training in accordance with MTP's and directives from higher headquarters.

c. Training is conducted in accordance with techniques prescribed in FM 5–5, FM 21–5, and TM 21–250.

31. ACTIVATION AND GENERAL TRAINING SCHEDULE. a. Fillers for organizations to be activated report directly from reception centers to EAUTC's. After 8 weeks of training certain selected men are sent to specialist

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schools while the remainder are sent to newly activated organizations or as overseas replacements. The activation and training schedule for an organization is as follows:

(1) On A-day (date of activation) a cadre of qualified men from other organizations is received. This is the group of key personnel around which the organization is built.

(2) From A-day to O-day (a predetermined date approximately 30 days after A-day) the organization receives 85 percent of its enlisted men. The men received during this period have received 8 weeks of training under MTP 5–1.

(3) At O-day the organization commences the remaining 5 weeks of training under MTP 5–1.

(4) Following MTP 5–1 the organization enters the unit training period of 11 weeks under MTP 5–5.

(5) Specialists join the organization during the entire training period until the organization is brought up to strength.

b. For airborne units the first 5 weeks only of MTP 5–5 are carried out at the EAUTC. The remaining 6 weeks are spent with the troop carrier command.

c. The schedules listed above are approximate with respect to time.

32. GENERAL TYPES OF TRAINING. Training falls into three general classifications: *basic, technical* and *tactical.* As indicated in paragraph 30, basic training applies to the individual soldier while technical and tactical training apply to both the individual and the unit.

33. BASIC TRAINING. This includes the following:

a. Disciplinary training to instill habits of obedience, promote teamwork, and develop morale and leadership.

b. Physical training to develop physique and harden the soldier for field service.

c. Training to teach the soldier how to care for himself and his equipment in the field.

34. TECHNICAL TRAINING. Technical training is designed to prepare individuals and units for the engineering tasks assigned to aviation engineers.

a. The initial phase of technical training is the training of the *individual specialist* in his regularly assigned task such as carpentry, welding, or equipment operation. At least two operators should be trained for each piece of equipment.

b. Following instruction of individuals, units are trained to execute tasks under appropriate commanders. These tasks should be of the type to be performed in the theater of operations. All phases of airdrome construction should be actually performed, not merely simulated. During this phase of training, emphasis must be placed on proper detailed planning and organizing of forces

to accomplish assigned tasks. To plan poorly or hastily is to defeat the purpose of organizational training. Tasks of the following types should be assigned:
(1) Construction of sections of common types of runway with different types of drainage, base course, and surface.
(2) Lay-out of runways and taxiways in varied types of terrain.
(3) Construction of dispersed hard standings.
(4) Lay-out, construction, and maintenance of facilities essential to air combat units, such as gasoline dumps, ammunition dumps, and shelters for personnel and equipment.
(5) Construction, maintenance, and operation of utilities.
(6) Camouflage of runways, hard standings, airplanes, and installations.
(7) Construction of defensive works at airdromes including weapon emplacements, obstacles, demolition emplacements, and mine fields.

c. Included in technical training of both individuals and units is the removal of land mines and booby traps. This subject is covered in detail in FM 5–31.

35. TACTICAL TRAINING. Tactical training prepares the unit for participation in combat and for furnishing security on the march, in bivouac, or while engaged in engineer work. This phase of training must not be neglected. Aviation engineers must be fully prepared for aggressive combat to protect construction projects.

a. The first phase of tactical training should impart to the individual—
(1) Thorough knowledge of all assigned weapons. Though an individual must specialize in the weapons with which he is equipped, every man must be able to use a rifle and bayonet. All personnel should be able to handle any organic weapon in an emergency. These include the pistol, carbine, M1 rifle, caliber .30 machine gun, caliber .50 machine gun, submachine gun, rocket launcher, and 60-mm mortar.
(2) The principles and technique of individual cover and concealment.
(3) Practice in scouting and patrolling by day and night.

b. The second phase of tactical training is the development of fighting teams. This includes instruction in—
(1) Technique of rifle fire.
(2) Antimechanized defense and antiaircraft firings.
(3) Principles of local security.

36. MAINTENANCE OF EQUIPMENT. Instruction in equipment maintenance is an important phase of training since the success of all construction tasks depends upon keeping equipment in operating condition. In a theater of operations facilities for maintenance and the supply of spare parts are limited. This fact must be recognized during the training period. Operators must learn preventive maintenance and maintenance procedures from the first day of training. (See par. 206 and app. VI.)

37. TRAINING LITERATURE AND AIDS. **a.** The primary texts for training are official War Department training publications issued in the form of Field Manuals (FM) and Technical Manuals (TM). Important changes in these manuals are published in the form of Training Circulars (TC). These publications form the basis for all instruction. They are listed in FM 21-6. Other training aids are listed in FM 21-7 (training films and film strips) and FM 21-8 (graphic training aids). In addition to official publications certain other references may be used in training. These include standard civilian texts used as construction handbooks and directives and memoranda circulated by higher headquarters.

b. Every organization must keep an up-to-date file of training publications which can be consulted readily by all members of the organization. *Every officer and noncommissioned officer engaged in training must be familiar with FM 21-5, 21-6, 21-7, and 21-8, so that the proper publications and aids will be used in training.*

c. Distribution of official training publications and aids is automatic. However, if an organization does not receive its full quota, necessary requisitions should be submitted through normal channels, as given in FM 21-6, 21-7, and FM 21-8. If difficulty is experienced in obtaining material through these channels, the Assistant Chief of Air Staff for Training, Army Air Forces, should be notified directly.

38. TRAINING NOTES. **a.** Training time for all organizations is so limited that careful planning is necessary to derive the greatest possible benefit from all periods of instruction. Training schedules should be published in time to allow instructors to prepare lessons thoroughly. Detailed programs for inclement weather must be drawn up so no training time is lost because of unfavorable weather.

b. Combat conditions should be simulated as closely as possible in training. It is particularly important that troops be trained to carry out all types of work at night as most military operations must be conducted under cover of darkness.

c. Visual training aids (FM 21-7 and FM 21-8) should be utilized as much as possible. Training films, film strips, and graphic aids now cover practically all basic and tactical training and many phases of technical training. They should be included in the training schedule and not be treated as fillers for inclement weather schedules.

CHAPTER 5

AIRBORNE AVIATION ENGINEERS

39. GENERAL. This chapter is a general outline of the mission, organization, equipment, training, and operations of airborne aviation engineer units.

40. MISSION. **a.** Airborne aviation engineer units are designed to provide quickly advanced landing fields for troop carrier and air-support operations. They are similar to other aviation engineer units, except that their organic construction equipment is light and can be transported by cargo plane or glider. They are employed for operations in which the normal heavy construction equipment cannot be transported to the desired site in the required time. Typical missions for airborne aviation engineer units are:

(1) As part of an airborne task force, to seize and rehabilitate enemy airdromes. These airdromes may be on the flanks or in rear of the enemy's front lines.

(2) As an airborne unit, to construct new advanced landing fields in areas in which cargo planes or gliders can land but which cannot be reached by overland movement.

(3) As part of an amphibious task force, landing on a hostile shore.

(4) As airdrome construction troops to accompany forward elements of ground force troops in areas in which heavy equipment is not sufficiently mobile to accompany the advance. In this situation transportation must be furnished for personnel and equipment.

b. At the present time the construction operations of airborne aviation engineer units are limited to favorable sites. Their organic equipment is not suited to extensive clearing or heavy earth work (see par. 44). However, new developments in the disassembly of heavier equipment into small parts for air transport (see par. 207) will enable airborne units to perform tasks of a much more comprehensive and difficult nature.

c. Airborne units are trained to use heavy construction equipment as well as their organic light equipment. When they are not on missions requiring the use of light equipment they may be employed as other aviation construction units, using equipment drawn from depot stocks or other organizations.

d. Since combat for self-preservation often may become a mission of airborne aviation engineer units, they are trained and equipped for the execution of that mission. Nevertheless, they are primarily service troops. Although adequately armed for their own security they should not be used as a combat force in the initial effort of seizing a field and reducing enemy defensive installations. An organization once committed to combat finds it difficult to withdraw and commence construction operations.

e. Airborne *aviaiton* engineer units should not be confused with the airborne engineer battalions which are components of the airborne divisions. The latter engineer units are parachute and glider troops and are equipped with hand tools only.

41. ORGANIZATION. **a.** Organization is given in T/O 5–455, 5–456, and 5–457. The battalion consists of a headquarters and service company, three construction companies, a medical detachment and a chaplain. Total strength is approximately 28 officers and 500 enlisted men.

b. The main organizational feature peculiar to airborne aviation engineers is the organization of the company. Each lettered company has three platoons; two of them are construction platoons while the third is a service platoon. Since the service platoon maintains and repairs all company transportation and equipment the company may operate independently of the battalion. However, when the company is on an independent mission additional equipment with operators normally is attached from headquarters and service company.

42. EQUIPMENT. **a.** Construction equipment and tools include items common to all engineer units as well as special equipment designed for transportation by cargo airplanes and gliders. Transportation is sufficient for administrative purposes only and is not provided for equipment and personnel. Communication equipment is limited to radio from battalion to company and from battalion to higher headquarters, to signal panels, signal flares, blinkers, and bicycle messengers. Armament consists of pistols, carbines, rifles, submachine guns, rocket launchers, and caliber .50 antiaircraft machine guns.

b. Major items of construction equipment include the following:

(1) Crawler tractor with bulldozer and winch (fig. 258).
(2) Rubber-tired tractor (fig. 252).
(3) Tractor-mounted, ⅓-cubic yard shovel loader (fig. 252).
(4) 1½-cubic yard scraper (fig. 257).
(5) ½-ton dump trailer (fig. 259).
(6) Towed road grader with 6½-foot moldboard (fig. 250).
(7) Sheep's-foot roller (fig. 255).
(8) Smooth roller (fig. 254).
(9) Rotary tiller mixer (fig. 253).

c. Items (4) through (9) above may be towed by either the crawler or the rubber-tired tractor. A ¼-ton truck may be used to tow the ½-ton dump trailer. The shovel loader (3) is mounted on the rubber-tired tractor.

d. A detailed list of equipment is given in table XXXVI, chapter 25. Also included in chapter 25 are illustrations of principal items of construction equipment.

43. TRAINING. **a.** The training of airborne aviation engineer units is conducted according to the principles given in chapter 4. Primary emphasis is placed on the *rapid rehabilitation and construction* of advanced landing fields. Combined training with airborne ground units is accomplished during the last phase of training under MTP 5–5.

b. Troops should be especially trained in—

(1) Emplaning and deplaning, including loading and securing supplies and equipment.

(2) Repair and operation of captured enemy weapons, transportation, and construction equipment. This is particularly important since only a limited amount of equipment can be carried in airborne operations.

(3) Communication with supporting aircraft, with emphasis on methods of identifying themselves.

Figure 4. Airborne aviation engineer troops loading grader into cargo plane.

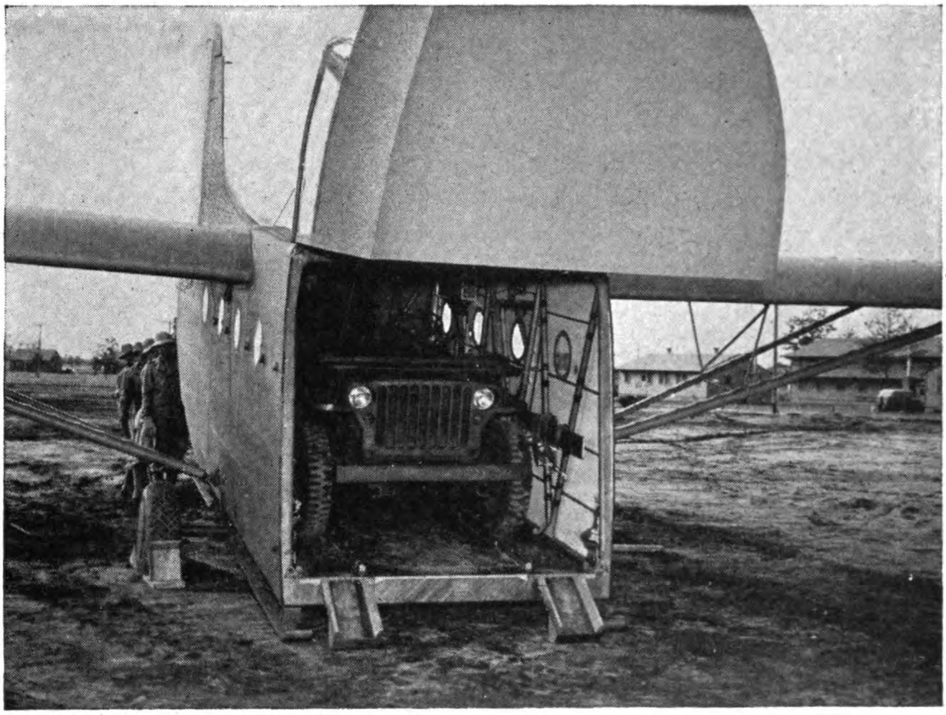

Figure 5. ¼-ton truck loaded into glider for air transport.

(4) Temporary employment as ground crew for air force traffic direction and servicing. At advanced landing fields airborne aviation engineer troops may be required initially to operate local air traffic, direct taxiing aircraft (see app. II), operate refueling facilities, place runway lighting, provide food for air crews, and operate other services.

c. Officers should be especially trained in—

(1) Emplaning and deplaning troops, equipment, and supplies.

(2) Organization of working parties for rapid execution of construction tasks immediately upon landing.

(3) Communication with supporting aviation.

(4) Administration, supply, and evacuation of units when normal transportation facilities are lacking.

(5) Planning and execution of tactical operations, particularly in defense of airdromes, requiring precise coordination with air forces, parachute troops, and supporting arms.

44. CONSTRUCTION LIMITATIONS. **a.** The most important item in construction of new advanced landing fields by airborne aviation engineers is selection of site. This point cannot be too strongly emphasized. The limitations of airborne equipment restrict operations to favorable locations. The success or failure of the construction task depends upon the judgment of the officer who makes the site reconnaissance.

b. The basic principles of site selection and advanced landing field construction (chs. 8 and 9) are the same for airborne troops as for other construction units. The only difference is in equipment capabilities and the limitations upon supply imposed by air transport. The site to be developed must have the following characteristics:

(1) The area should be fairly level and open. It must be free of large rocks and boulders and similar obstructions and have only small, scattered trees. Earth-moving requirements must not be excessive.

(2) The soil should be a well-drained, nonplastic type containing a high proportion of granular material, and must not be too hard for light equipment to work. Soils with considerable clay or silt must be avoided unless limited operation in dry weather is contemplated. The subgrade must be capable of supporting traffic initially since it will not be possible to construct a complete base course over the entire runway.

(3) The area must have good natural drainage. Extensive ditching is not possible.

(4) If airborne construction troops are to be used, cargo planes or gliders must be able to land after a limited amount of hand clearing.

c. The organic equipment of airborne aviation engineers is suitable for all types of rehabilitation work unless the enemy has been able to execute extensive demolitions. Airborne aviation engineer troops are trained to remove mines and booby traps and other obstacles; however, if the area is thoroughly mined and booby-trapped, it may be necessary to select another site rather than repair the existing one.

45. TACTICAL REQUIREMENTS. **a.** During construction or rehabilitation work by airborne troops it is essential that air superiority be maintained over the site. Transport planes are particularly vulnerable during loading and unloading and must also be protected during flight.

b. Captured airdromes are nearly always exposed to vigorous counterattacks by enemy ground troops as well as enemy aircraft. Protection against ground and air attack should be furnished by troops other than airborne aviation engineers whenever possible. However, engineer troops always establish local security for their own working parties, even though the site is guarded by other units.

46. TYPICAL OPERATION. **a.** The following example is a typical operation of airborne aviation engineers in the theater of operations.

(1) MISSION. To construct an advanced landing field on the flank of the enemy lines. The general area in which the field is to be built is visited by occasional friendly and enemy patrols and cannot be reached by overland travel of construction equipment in the limited time available. Some native hand labor is available in the area.

(2) FIRST PHASE. Reconnaissance of the general area by an experienced

engineer officer and pilot from the air, followed by ground reconnaissance by the engineer. Site selected and general lay-out of landing strips established on aerial photos by engineer and his party.

Figure 6. 1½-cubic yard scrapers used to excavate ditch.

Figure 7. Loading ½-ton dump trailer with shovel loader on rubber-tired tractor.

(3) SECOND PHASE. Rough strip for a few cargo planes to land cleared by natives under supervision of engineer's party. Advance party for airborne engineer battalion lands with tractor, hand tools, and demolitions. This party

Figure 8. Grading an advanced landing field.

***Figure** 9. Compacting with an airborne tractor-drawn sheepsfoot roller.*

prepares bivouac area and weapons emplacements and clears strip for landing of additional cargo planes.

(4) THIRD PHASE. One complete company of engineers lands on strip cleared by advance party. This strip is kept open for continued use by cargo planes while a second landing strip is built for fighter planes. As soon as the second strip can be used fighters land, refuel, obtain ammunition, and take off. They are not parked at the field.

(5) FOURTH PHASE. Taxiways and hard standings are constructed so fighter planes can be based at the field. Airdrome now is in 24-hour operation for fighters.

(6) FIFTH PHASE. Engineer aviation battalion with heavy equipment arrives at site by overland travel or air transport. Runways consisting of base course of select material from local gravel pits are built on fighter landing strips. Taxiways are given a similar base course. Operational facilities are improved. Advanced landing field becomes an all-weather field airdrome.

b. In the capture of enemy airdromes the troops which actually seize the airdrome may be ground forces or airborne troops. In either case the airborne aviation engineer troops should not reach the site until hostile resistance has been completely overcome. Combat engineers may clear the way for aviation engineers by removing mines and other obstacles, filling bomb craters, and preparing a suitable landing strip for cargo planes or gliders.

PART TWO
CONSTRUCTION

CHAPTER 6
CONSTRUCTION IN THEATER OF OPERATIONS

47. BASIC CONSIDERATIONS. All construction in the theater of operations is temporary and is limited to *bare necessities. Economy of time is the primary consideration;* in addition, wartime construction requires economy of *materials, labor,* and *transportation.* Quality, safety, convenience, appearance, and cost, which are important in civil construction, are subordinated. Therefore, military airfields are designed with lower standards than are acceptable for peacetime civilian aviation. To minimize the effects of scarcity of materials and unforeseen tactical and technical developments there must be readiness and ability to improvise and substitute. Closely allied to this is full use of local materials and native labor.

48. SPEED OF CONSTRUCTION. Rapid construction of airdromes requires maximum and efficient use of the equipment organically assigned to aviation engineer units. All planning and direction of work should be pointed to this end. Hand labor by troops or natives should be used to supplement machines, not to replace them. Where there is more work than available equipment can accomplish, the equipment should be assigned to the tasks having the highest priority.

49. CARE OF EQUIPMENT. Care of equipment is the vital concern of all officers and men. Engineers in the forward area estimate the earth-moving capacity of a D-8 dozer as roughly equal to the output of 1,000 local laborers. At this rate, loss of one day's time by this machine from improper care is the loss of 1,000 man-days of work. By the same measure the responsibility of a D-8 operator is the same as that of the supervisor of 1,000 laborers. Proper training of operators; regular and thorough lubrication, inspection, and maintenance; proper use of equipment; and stocking of adequate spare parts must be stressed. It is not possible to overemphasize the importance of proper maintenance and handling of equipment. (See ch. 25.)

50. DISPERSION. All facilities constructed in the theater of operations are dispersed to minimize damage from bombardment. This principle is applied in establishing the locations of all installations and equipment at an airdrome. The extent of dispersion varies with each situation. It should be no greater than is required for the proper degree of protection. Too great dispersion of aircraft, for example, means a waste of time and fuel getting planes to and from the landing strip, and increases the possibility of sabotage of planes.

51. USE OF LOCAL RESOURCES. a. Existing facilities. New construction is minimized by using existing facilities, such as buildings and roads, where practicable.

b. Local materials. A study of methods and materials used by the natives often yields valuable clues for aidrome construction. Inspection of local road construction may disclose important data on drainage or subgrade that are helpful in locating and designing an airdrome in the same vicinity. Road surfacing may indicate the availability of a local material unusual but satisfactory for the base course of runways. Examples are iron ore, caliche, volcanic cinders, and lime rock. The native style of building construction may be adopted for the purpose of utilizing native labor and building materials, and camouflage (fig. 10).

c. Local labor. Local labor may be employed advantageously for a variety of tasks, releasing trained troops for more complicated technical duty (fig. 11). Using natives may increase the risk of sabotage and disclosure of information, but it is a stabilizing influence economically. Generally it is better to employ labor in accordance with local customs rather than to impose American practices.

d. Local equipment. Local equipment, such as rock crushers, rollers, trucks, and farm machinery is valuable for most operations in airdrome construction. Advantageous use should be made of any available equipment whenever it is needed (fig. 38).

52. STAGE CONSTRUCTION. a. A complete field airdrome is a major construction project (par. 75). However, by proper planning and by limiting

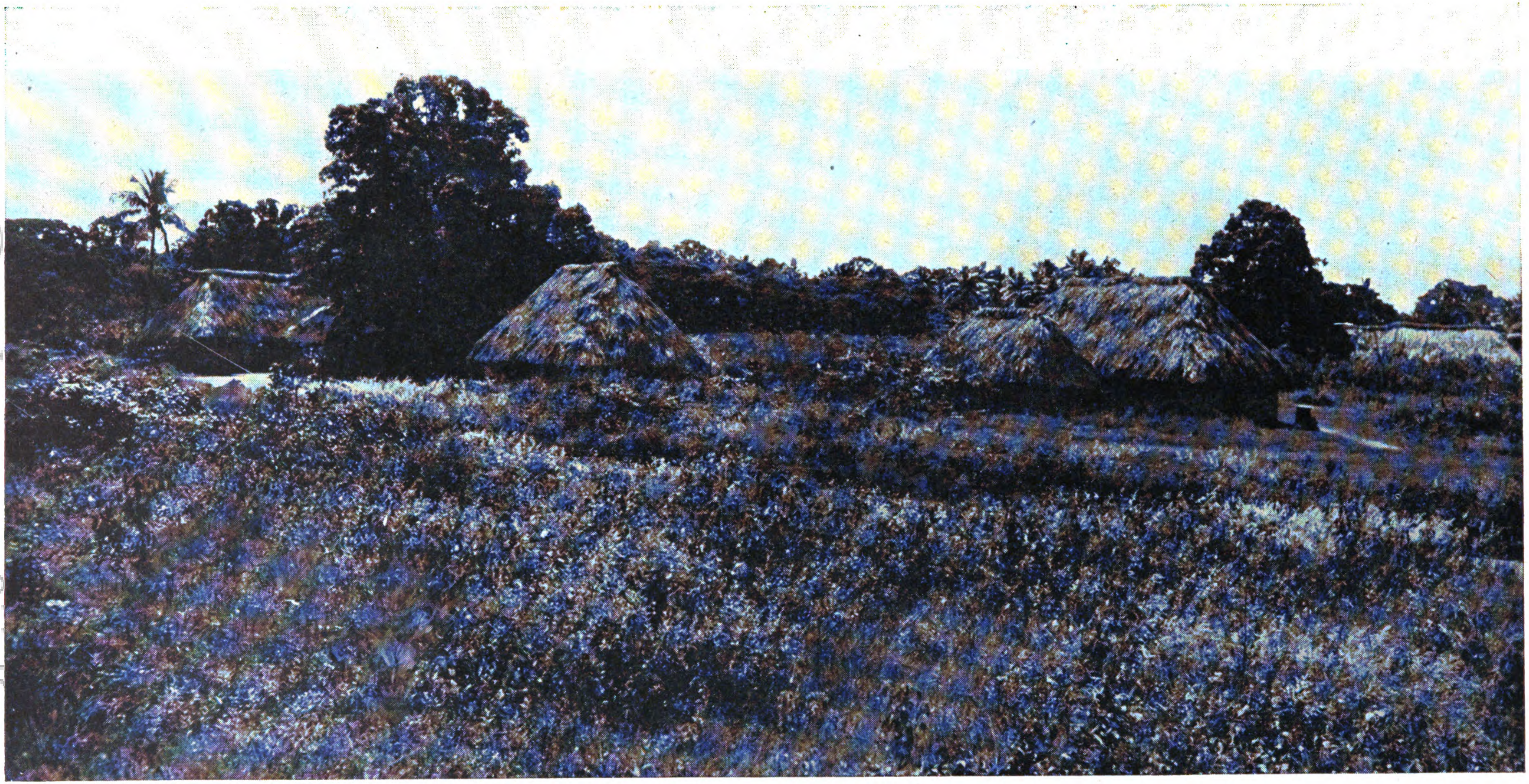

Figure 10. Native type buildings used by aviation engineers.

Figure 11. Local labor often is used to supplement troops and equipment.

construction to minimum essentials, it can support air operations at an early date after construction starts. Subsequent improvements are made, during use, by maintenance or by additional construction as required. Having a master plan as a general guide assures that work completed in each stage will be utilized in subsequent improvements and extensions (figs. 12 and 13).

b. There are many ways of applying the principle of stage construction in planning and constructing an airdrome. The first stage always consists of furnishing the barest essentials for plane operations. Until this is accomplished the airdrome is useless for military operations.

c. In general, there are three broad stages of development through which an airdrome may go. Some airdromes never are developed beyond the first stage; others are improved to the second or third stage. The decision in each case is made by the air force commander, based on his strategic and tactical plans. It is impracticable to set up standard requirements for each stage because they vary with each situation according to military requirements, transportation and supply, relative proximity to the enemy and our own forces, prevailing weather, soil and drainage conditions, and other technical factors. To visualize this, contrast conditions in the Pacific islands with those in Alaska, Europe, Africa, or Asia. However, the *general* scope, purpose, and priority of each stage usually are the same in any situation, as follows:

(1) FIRST STAGE. Purpose: to provide essential facilities for air operations at the earliest possible date. This is the emergency period. In some cases merely a smoothed, drained, and compacted-earth landing strip may be sufficient; in others considerable clearing, draining, grading, and surfacing with local natural material or steel landing mat may be needed. The peak has passed when a serviceable landing strip with some taxiways and hard standings has been provided, even though the facilities are temporary.

(2) SECOND STAGE. Purpose: to increase capacity, safety, and efficiency of air operations by improving, adding, and extending operational and technical facilities, and to improve security by dispersion, camouflage, and protective construction. Construction during this stage likewise should be planned by stages, making full use of all initial work. For example, a smooth, compacted, and drained subgrade may serve aircraft temporarily. Meanwhile, base and surfacing material may be prepared and stock piled, or construction may proceed on other parts of the airdrome if properly coordinated with air operations. Similarly, a field airdrome may be required for use when the base is completed but before the surface is constructed. In other cases an airdrome originally designed for use of lightweight or mediumweight airplanes may have to be improved to carry heavier airplanes, or a steel runway used initially may be replaced with some other type of surface.

(3) THIRD STAGE. Purpose: to provide facilities for administration and comfort of personnel, such as buildings, utilities, messing, bathing, and recreational facilities.

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CHAPTER 7

GENERAL CRITERIA FOR AIRDROMES

53. DEFINITIONS. **a.** *Airdrome* is the general term for any area of ground used for air operations by military aircraft.

b. An *advanced landing field* is a hastily constructed temporary airdrome near the front (fig. 12). Usually it has one landing strip and the barest essentials for servicing aircraft. As occupancy continues it may be improved progressively into a field airdrome. (See figs. 12 and 13.)

c. A *field airdrome* is an all-weather airdrome with facilities for supply, service, and shelter of aircraft, and built for continuous wartime use. All installations and facilities are dispersed to make them unremunerative targets. Construction is held to the minimum consistent with military necessity. (See fig. 13.)

d. An *air base* is an area command for supply and administrative purposes consisting of a parent airdrome, or *base airdrome,* and one or more smaller field airdromes in the surrounding territory. The latter are called *auxiliary airdromes* or *satellite fields* because they depend upon the base airdrome for major supply and repair facilities.

e. The following terms describe the parts of an airdrome used for plane operations (figs. 12, 13, 14, and 16):

(1) A *landing strip,* is the cleared, drained, and graded strip used by planes in landing and taking off. Its length includes the runway and the *clear zones,* also called *end zones,* built at each end. The clear zones are prepared for occasional use by planes that land prematurely or overrun the runway. The landing strip width includes the *runway, shoulders,* and any *graded areas* adjacent to the sides of the shoulders. The runway is a stabilized, paved, or steel-surfaced strip along the center line of the landing strip on which planes normally land and take off. To the sides of the runway are shoulders which are prepared for occasional use by planes and for "wheels-up" landings of damaged planes. Separate crash landing strips sometimes are constructed.

(2) An *approach zone* is a trapezoidal area extending outward from each end of a landing strip, within which no natural or man-made object may project above the *angle of glide.*

(3) The *safety-clearance zone* is the area on each side of a landing strip within which no natural or man-made object, except a control tower, may project above the *side-clearance angle.*

(4) A *taxiway* is a strip prepared for planes traveling on the ground between landing strips, hard standings, or aprons. Its width includes a stabilized, paved or steel-surfaced central strip and shoulders. A *stub-end taxiway* is one connecting a hard standing to the main taxiway.

(5) A *hard standing* is a stabilized, paved, or steel-surfaced area on which an airplane is parked. Hard standings are dispersed over the ground area to the sides of a landing strip.

(6) An *apron* is a stabilized, paved, or steel-surfaced area for the temporary parking of aircraft other than at hard standings. An *alert apron,* also called *assembly apron,* is used for the assembly of planes on the alert for rapid take-off. It adjoins a side of the runway at one or both ends. A *service apron* is used for aircraft repair and service not performed at hard standings.

f. The following terms apply to the structural or wheel-load supporting elements of runways, taxiways, hard standings, aprons, and roads (fig. 15):

(1) *Subgrade* applies to the natural soil in place or to fill, upon which a pavement or base is constructed. Where the upper 6 to 9 inches of subgrade is stabilized by admixture or other natural or commercial material followed by extra compaction, it is called *stabilized subgrade* and is considered part of the base course.

(2) *Soil stabilization* includes any process which produces soil base courses of desired structural stabilities.

(3) *Base* applies to the course or combined courses of specially selected soils, treated soils, or aggregates, placed and compacted on the subgrade to increase the wheel-load capacity.

(4) A *surface-treated base* is one covered with a bituminous surface treatment (ch. 18) to bind and waterproof the surface of the base.

(5) *Pavement* applies to a bituminous course or portland-cement concrete slab superimposed upon a subgrade or base to serve as an abrasion- and weather-resistant structural medium. Bituminous pavements are classified as *flexible type,* and portland-cement concrete as *rigid type.*

54. CLASSIFICATION OF AIRDROMES. Airdromes are classified in terms of their stage of development as advanced landing fields, field airdromes, or base airdromes, as defined in paragraph 53. They also are classified as *fighter* or *bomber* airdromes according to the type of plane they can accomodate. The clasifications *dry-weather* and *all-weather* are used to differentiate airdromes according to the restrictions imposed by weather conditions upon their use for air operations. However, the distinction between them is not definite and is modified by the intensity of use by aircraft. For example, an airdrome runway may soften in wet weather or loosen in dry weather to a degree that necessitates temporary curtailment of air operations. In this case it would be described as a restricted wet-weather or a restricted dry-weather airdrome.

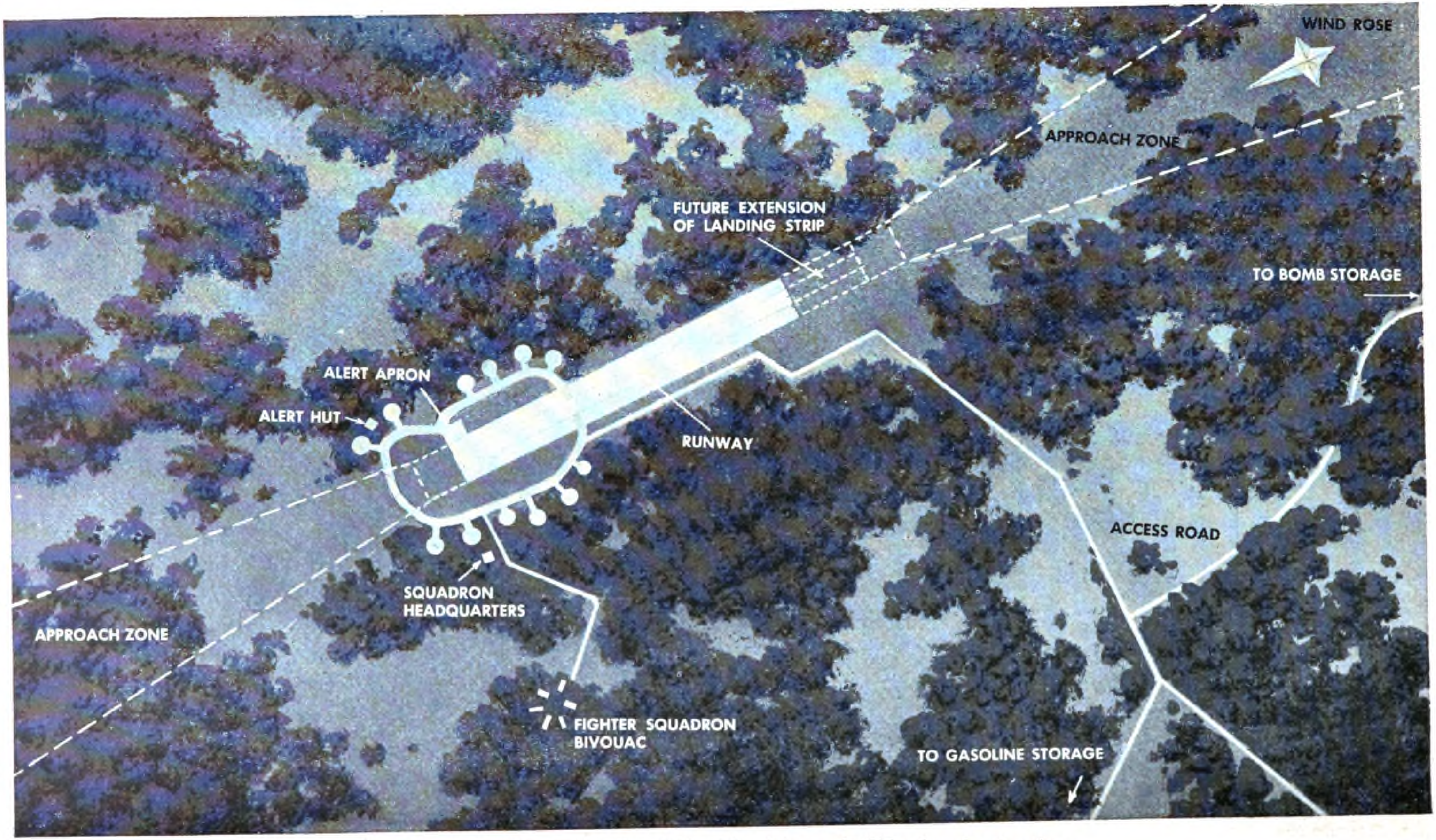


Figure 12. Advanced landing field with minimum facilities for air operations.
See figure 13 for illustration of field airdrome developed from it.

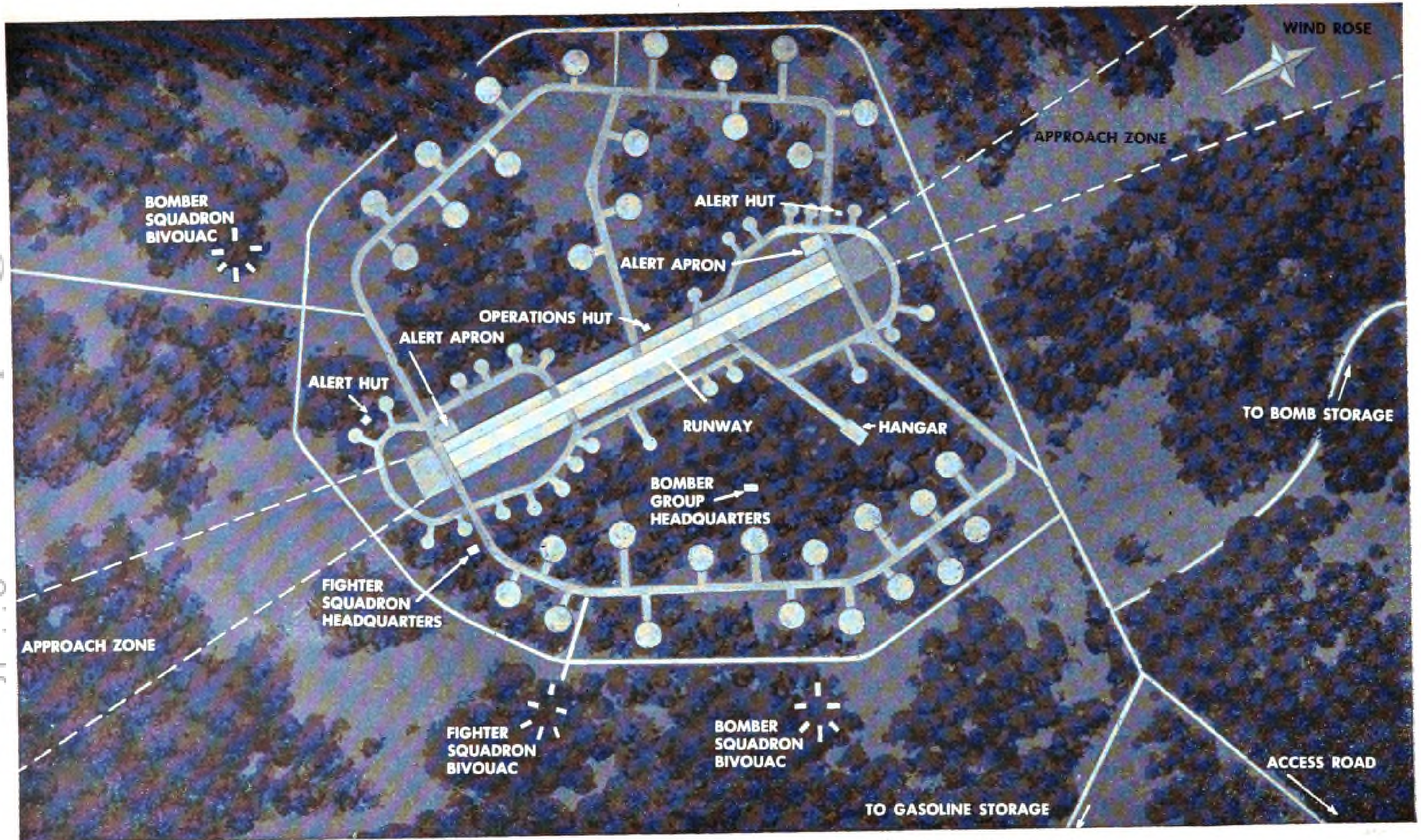


Figure 13. Field airdrome developed from advanced landing field shown in figure 12.

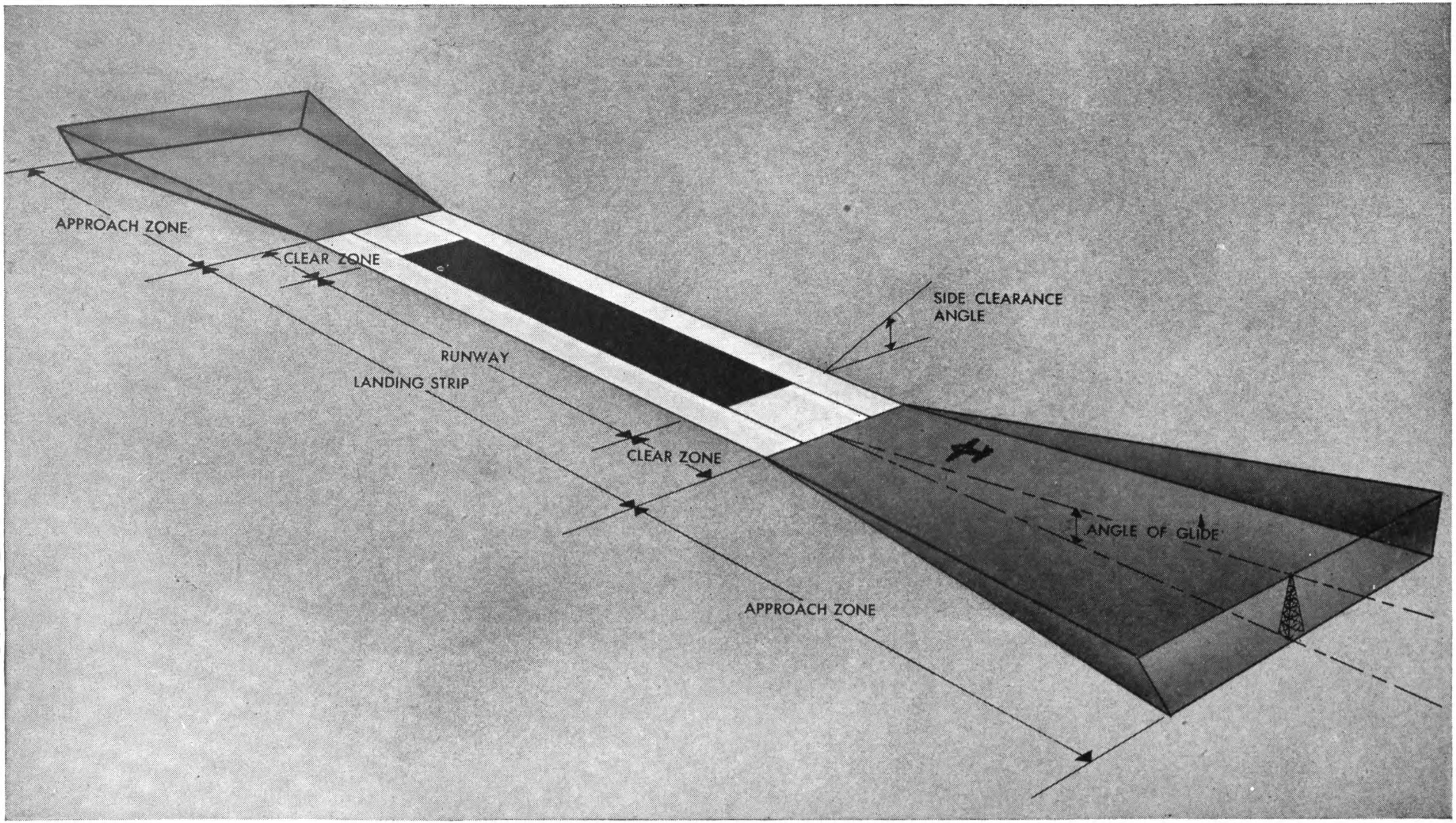


Figure 14. Landing strip showing runway, clear zones, and approach zones.

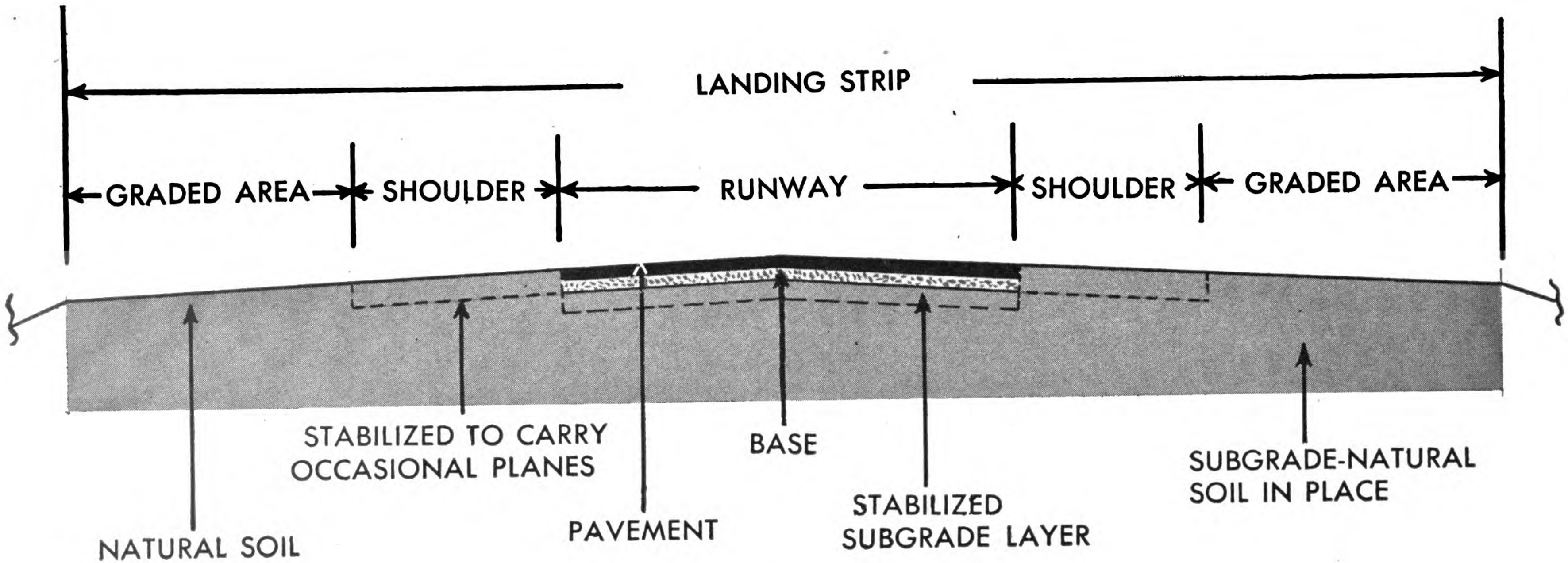


Figure 15. Cross section of landing strip.

55. RAISING THE CLASSIFICATION OF AN AIRDROME BY STAGE CONSTRUCTION. The classification of an airdrome can be raised by improving it by stage construction. For example, by lengthening the landing strip and strengthening the runway a dry-weather advanced landing field for fighters may be improved to accommodate bombers. Similarly, by adding taxiways and hard standings and improving facilities for supply, service, and repair of aircraft an advanced landing field is developed into a field airdrome. (See figs. 12 and 13.)

56. DIMENSIONS, GRADES, AND CLEARANCES. Recommended minimum dimensions and grade criteria for landing strips, runways, and approach zones are summarized in figure 16 and table I; for taxiways, in figure 17 and table II; and for hard standings, in figure 18. These are not fixed standards but represent the normal minimum for air operations and should be provided wherever possible.

57. LAY-OUT CRITERIA. a. Landing strips. (1) The center line of the main landing strip is laid approximately in the direction of the prevailing wind. Wherever possible the deviation should not exceed $22\frac{1}{2}°$. Its exact position and direction are adjusted to avoid any fixed obstructions in the approach zones and to keep the amount of clearing, draining, and grading to the minimum consistent with necessary strength and other requirements for operations. If the site is subject to variable winds, or to storm winds materially different in direction from the prevailing wind, a second landing strip may be required in the general direction of such winds. For dispersion these two landing strips should be arranged in an open V or open T pattern, not crossed in an X-pattern. Their relative positions should provide minimum interference and hazard to air operations in the adjacent approach zones.

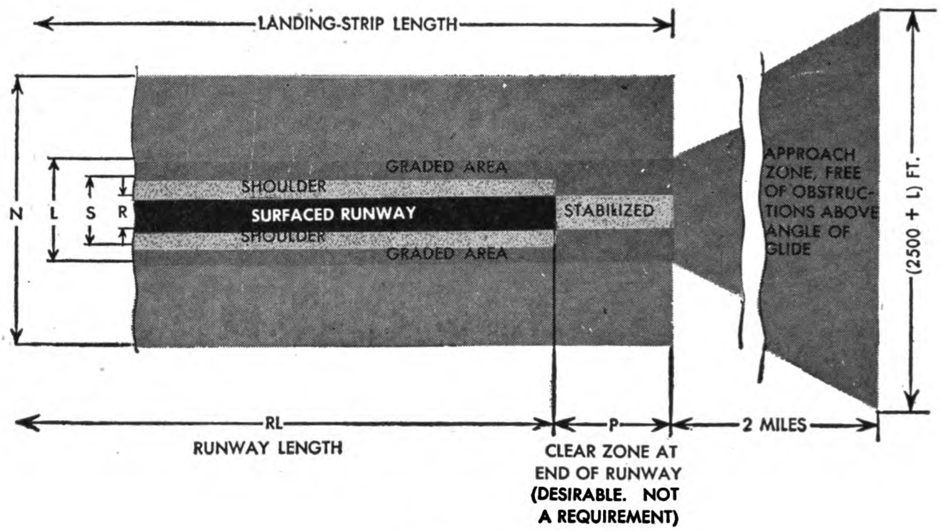
(2) Where storm winds are not a factor and more than one landing strip is required, a parallel arrangement often is used. Center lines must be exactly parallel and should be at least 500 feet apart. A parallel landing strip or a taxiway paralleling the landing strip is needed where the number of planes assigned to the airdrome overtaxes the capacity of a single landing strip. A parallel arrangement also is desirable where both fighters and bombers operate from the same airdrome (fig. 19③).

b. Taxiways. (1) Taxiways are laid out to provide rapid circulation of aircraft between dispersed hard standings and the landing strip (figs. 12, 13, and 19). Usually a main loop is laid out first, connecting near the ends of the landing strip. Sometimes the first taxiway parallels the landing strip. Other loops are added as needed. The loop principle is important to provide alternate routes of travel, so planes at hard standings will not be blocked from the landing strip by a direct bomb hit at any point on the taxiway. Taxiways generally are laid out as a series of straight lines joined by horizontal curves.

Table 1. Recommended dimensions and clearances for airdromes. (*Refer to fig. 16.*)

Type of aircraft	Length (feet)		Type of location	Width (feet)			
	Runway length at sea level*	Clear zone at each end of runway		Runway	Runway and shoulders	Landing strip	Safety clearance zone
	RL	P		R	S	L	N
	Minimum	Desired		Minimum	Minimum	Minimum	Minimum
Fighters and light bombers, such as P-38, P-39, P-40, P-47, P-51, A-20, A-24, A-36. Cargo, such as C-47, C-53, C-60.	4,000	500	Wooded or jungle	100-150	200-300	300-400	1,000
			Open or desert	150	300	300-500	1,000
Medium and heavy bombers, such as B-25, B-26, B-17, B-24. Cargo, such as C-45, C-46, C-54.	5,000	1,000	Wooded or jungle	150	250-300	300-400	1,000
			Open or desert	150	300	300-500	1,000
Superbombers, such as B-29. Cargo, such as C-74.	7,000	1,000	Wooded or jungle	200	300-400	400	1,000
			Open or desert	200	300-500	500	1,000

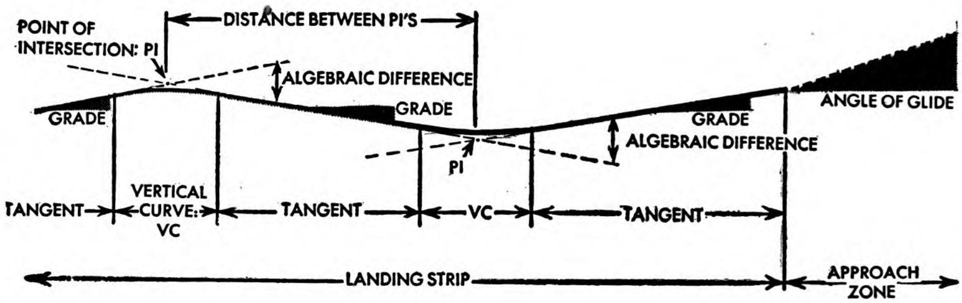
* Length of runway is increased 10 percent of sea-level length for each 1,000 feet of elevation of site above sea level. In regions of prevailing high temperature or of prevailing low atmospheric pressure an additional 10 percent is desirable. Recommended minimum lengths of landing strips at advanced landing fields without runways are same as minimum runway lengths.



PLAN

NOTES:

1. RUNWAY EXTENSION IN CLEAR ZONE STABILIZED TO CARRY OCCASIONAL PLANES.



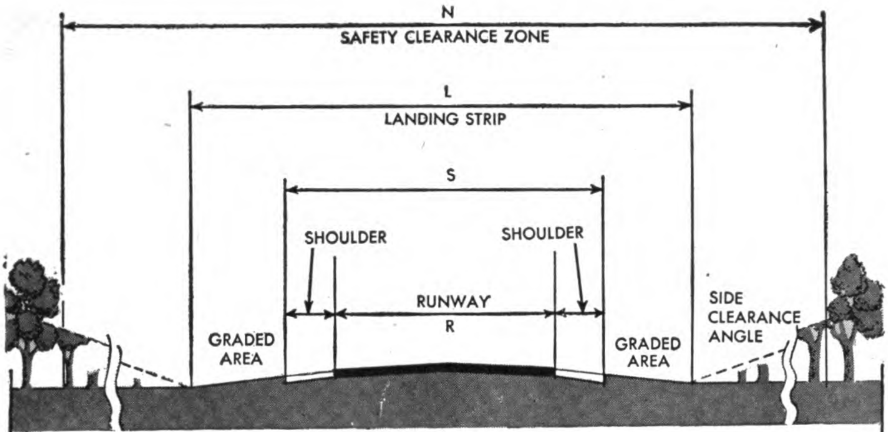
CRITERIA FOR LONGITUDINAL GRADE ALONG CENTER LINE OF LANDING STRIP.

1. DISTANCE BETWEEN PI'S NOT LESS THAN 1,000 FT.
2. VERTICAL CURVES . . : MINIMUM LENGTH 666 FT. PER EACH 1% ALGEBRAIC DIFFERENCE.
3. LONGITUDINAL GRADE . . . NOT GREATER THAN 1% FOR HEAVY BOMBERS AND NOT GREATER THAN 1½% FOR LIGHTER AIRCRAFT.
4. ANGLE OF GLIDE . . . OBSTRUCTION-FREE SLOPE 40 TO 1 IS DESIRED. MILITARY NECESSITY MAY REQUIRE STEEPER SLOPE BUT IN NO CASE SHALL IT BE STEEPER THAN 20 TO 1.
5. VISIBILITY . . . THERE MUST BE UNOBSTRUCTED VIEW FROM ANY POINT 10 FT. ABOVE RUNWAY TO ANY OTHER POINT 10 FT. ABOVE RUNWAY FOR LENGTH OF RUNWAY, BUT NOT OVER 7,000 FT.

① *Figure 16. Criteria for landing strips and related elements. (See table I.)*

One exception is that to reduce earthwork, contours may be followed. Another is that for planes with poor vision straight ahead, such as some fighters, the entire taxiway system may be constructed on long-radius curves.

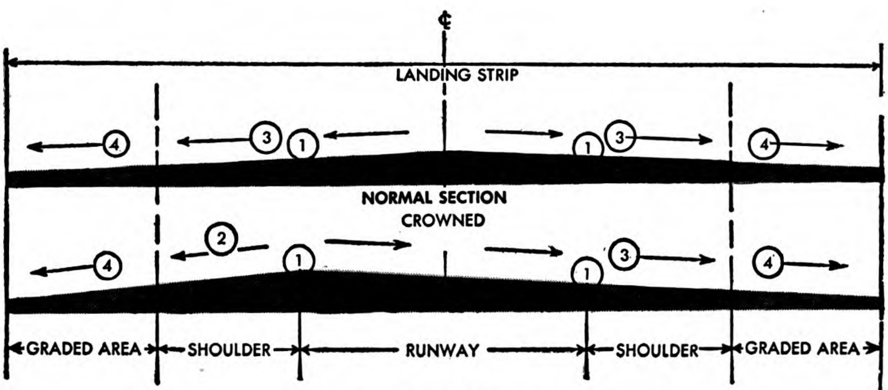
(2) Taxiways in prolongation of the runways are undesirable as these areas



CROSS SECTION

NOTES:

1. SHOULDERS
   STABILIZED TO CARRY ADDITIONAL PLANES.
2. GRADED AREA
   GRADED, COMPACTED, AND DRAINED TO CARRY PLANES EXCEPT DURING WET WEATHER. NO OBSTRUCTION OF ANY KIND PERMITTED.
3. SAFETY CLEARANCE ZONE
   NO GRADING EXCEPT AS SPECIFICALLY REQUIRED BY AIRDROME COMMANDER. NORMALLY TREE TOPS OR OTHER OBJECTS SHOULD BE REMOVED IF THEY PROJECT ABOVE A 7 TO 1 SLOPE FROM EDGE OF LANDING STRIP. CONTROL TOWER PERMITTED.



ALTERNATE SECTION
CROSS SLOPED

① PERMIT NO PONDING OF SURFACE WATER AT EDGE OF PAVEMENT.
② SURFACE DRAINAGE OF SHOULDER SHOULD BE AWAY FROM RUNWAY PAVEMENT.
③ SLOPE OF SHOULDER SAME AS RUNWAY.
④ SLOPE OF GRADED AREA NOT LESS THAN SLOPE OF SHOULDER AND MAY BE ½% MORE.

CRITERIA FOR CROSS SLOPE

SURFACE	SLOPE	
1. COMPACTED EARTH AND BITUMINOUS SURFACES OTHER THAN ASPHALTIC CONCRETE	1½ (MIN.) 2% (MAX.)	FOR REGIONS OF LIGHT PRECIPITATION, TRANSVERSE SLOPE MAY BE 1% MINIMUM.
2. ASPHALTIC CONCRETE	1½%.	
3. PORTLAND CEMENT CONCRETE	1% (MIN.) 1½% (MAX.)	

SUBGRADE

SUBGRADES ARE CROSS SLOPED, PREFERABLY SAME AS FINISHED SURFACE BUT NOT LESS THAN 1%

② *Figure 16. Continued.*

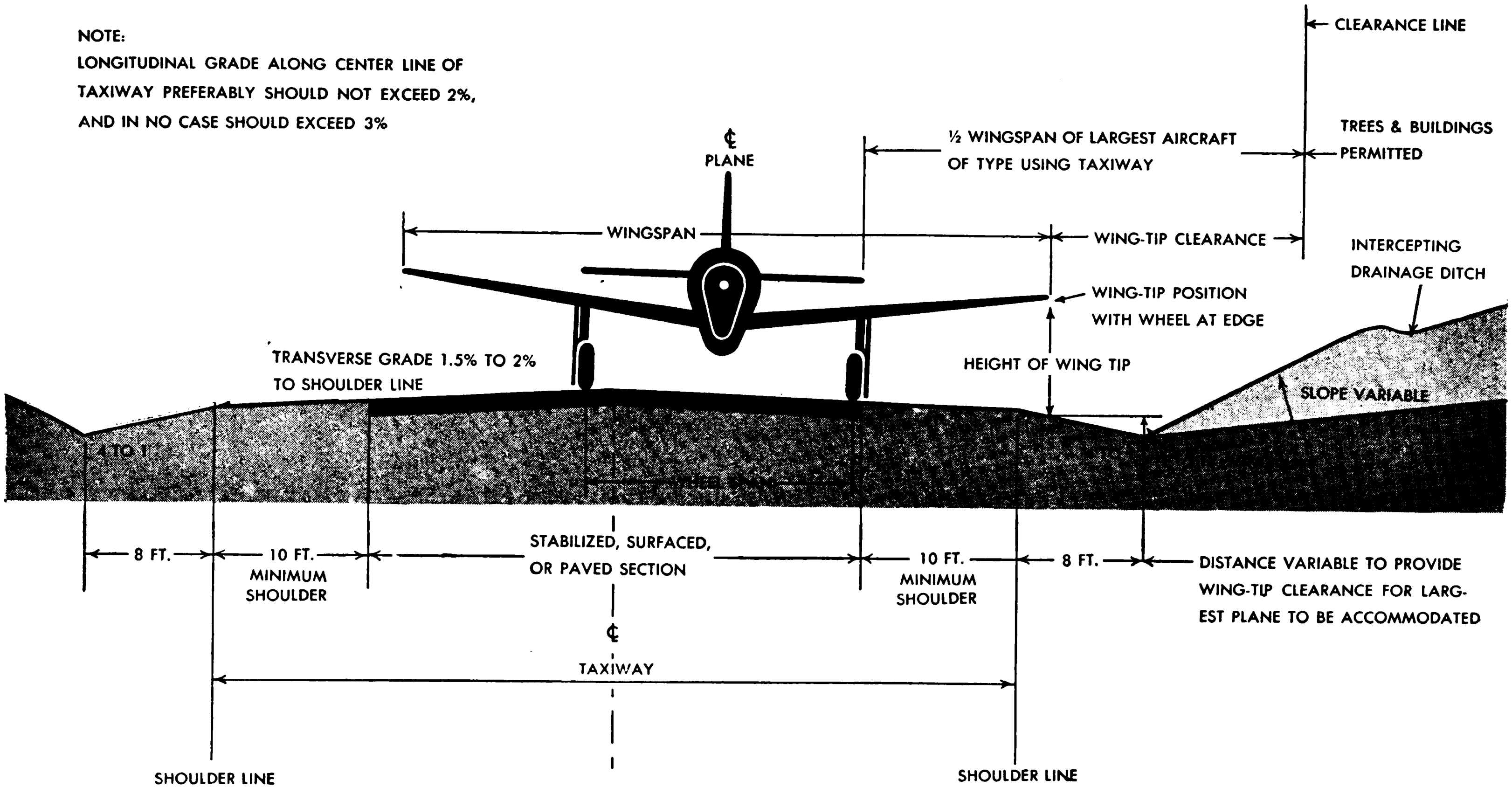


Figure 17. Criteria for taxiways. (See table II.)

Table II. Recommended widths and clearances for taxiways (refer to fig. 17).

Type of aircraft	Minimum width (feet)*		
	Stabilized, surfaced, or paved section	Between shoulder lines	Between clearance lines
Fighters and light bombers, such as P-38, P-39, P-40, P-47, P-51, A-20, A-24, A-36. Cargo, such as C-47, C-53, C-60.	30	50	Cleared zone on each side of taxiway extends out a distance, measured from edge of stabilized, surfaced, or paved section equal to one-half the wing span of largest aircraft using airdrome.
Medium and heavy bombers, such as B-25, B-26, B-17, B-24. Cargo such as C-45, C-46, C-54.	50	70	
Superbombers, such as B-29. Cargo, such as C-74.	75	95	

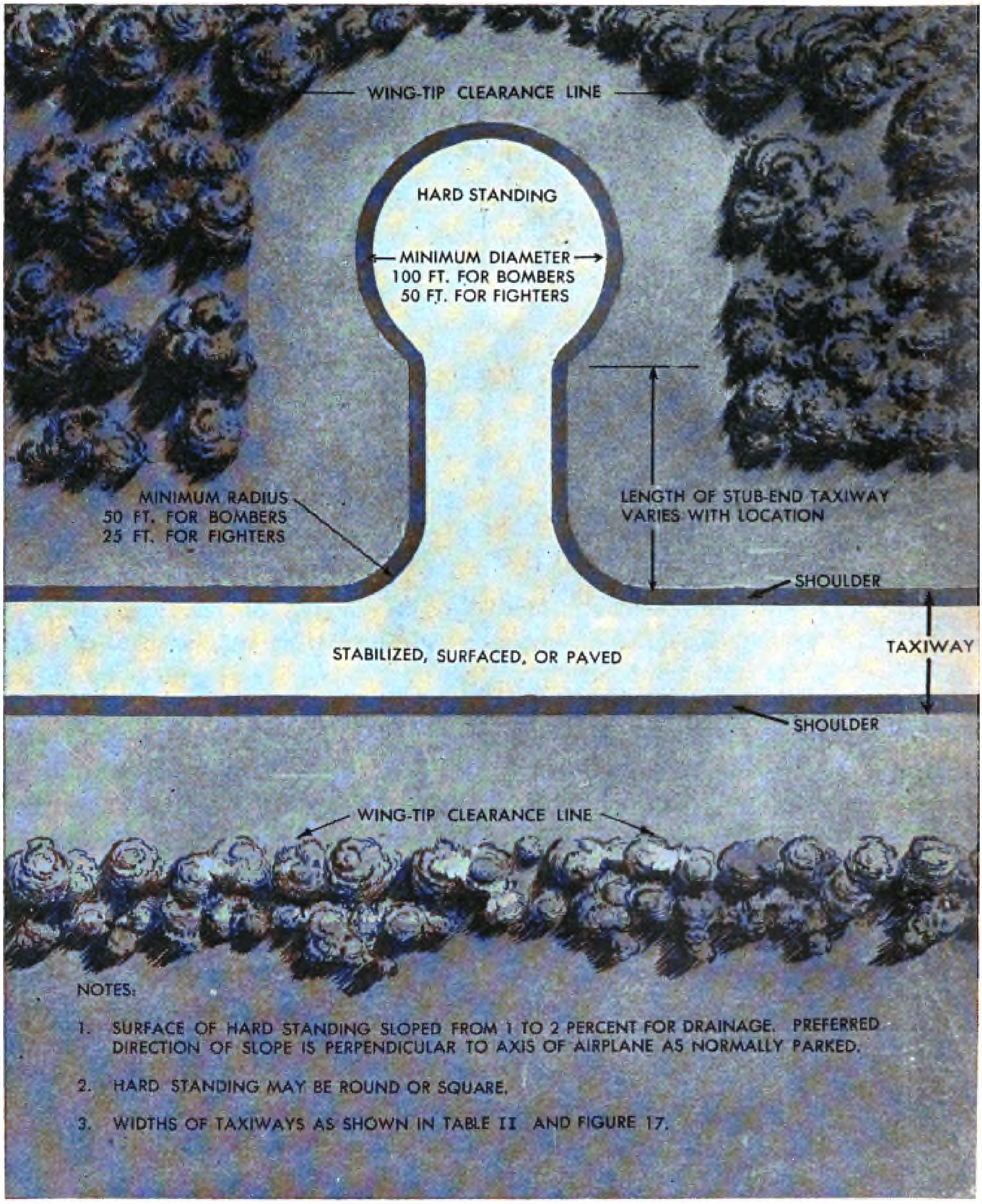
* Increase widths 10 feet on sharp curves.

receive many bombs intended for the runway. Stub-end taxiways to hard standings should be of varying lengths to avoid lining up of hard standings in either strafing or bombing runs. Taxiways should be widened and flared where they join the landing strip. Junctions between taxiways and between taxiways and landing strips normally are at right angles to afford good visibility of cross traffic to approaching planes. However, in some cases straight sections of taxiway, about 800 feet long and intersecting the ends of the runway at about 30° with the runway prolongation, are used to permit planes to reach and run onto the runway with little decrease in speed.

c. Hard standings. (1) These always are dispersed with a spacing of 300 to 500 feet depending upon the size of the planes, the nature of the terrain, and the area and construction time available. Wherever possible, locations are selected to take advantage of terrain and natural cover for protection and concealment. Hard standing locations should be staggered so that they do not line up in any direction to offer a remunerative target. This also applies to locations in the edges of woods.

(2) Hard standings for fighter planes generally are located near the ends of the runway, especially the down-wind end. Bomber hard standings are located at greater distances, but not more than necessary for satisfactory dispersion and concealment. Too great dispersion increases the amount of taxiway construction, complicates the problem of protecting outlying planes against sabotage, causes overheating of engines previous to take-off, and adds to operational difficulties in that time and fuel are wasted and airplane engines and landing gear suffer extra wear.

(3) The required size and shape of hard standings depend upon type of plane and turning characteristics, and upon the method of putting the plane into



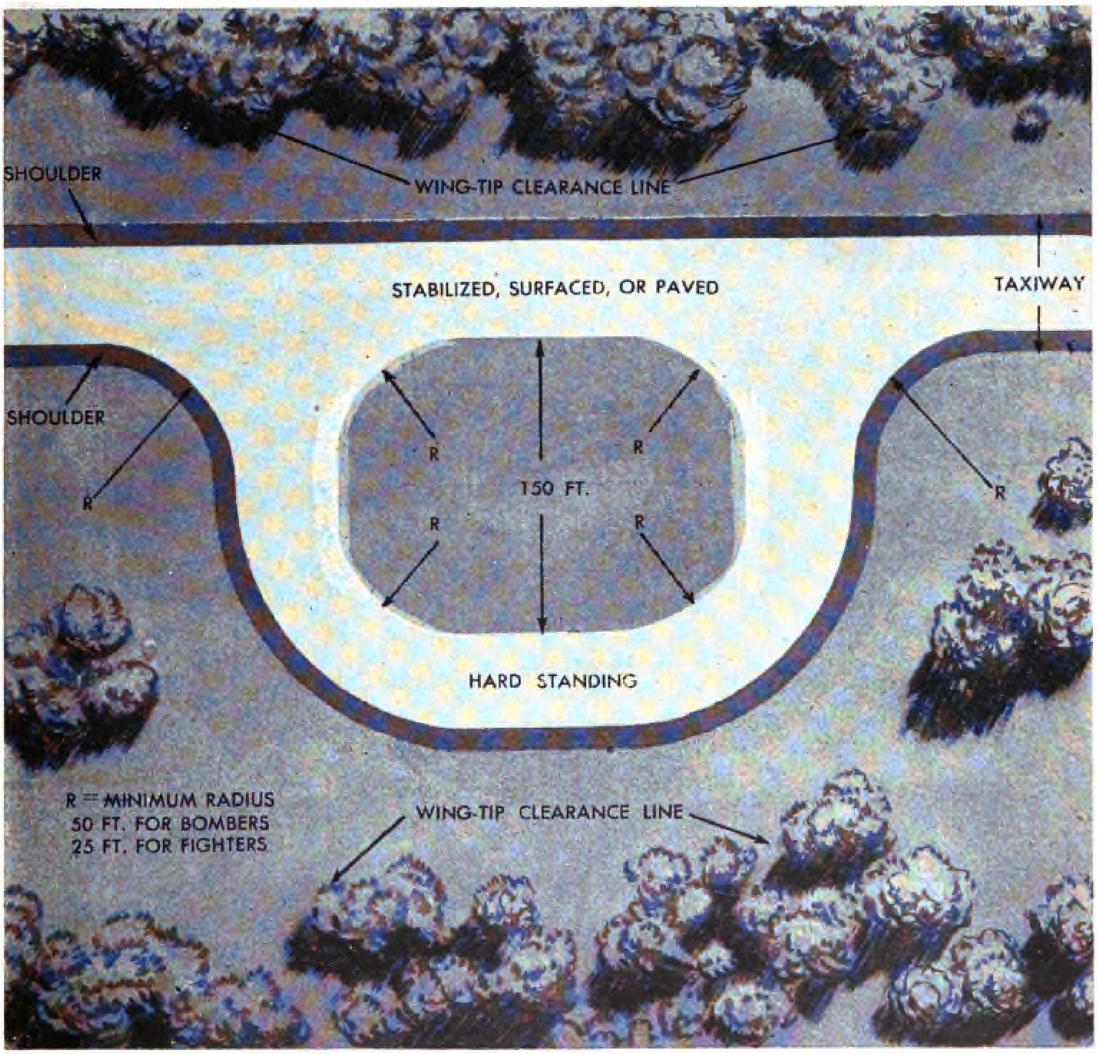
① *Taxi-in-and-turn type.*
Figure 18. Hard standings.

position. Data on airplane dimensions and turning characteristics are given in table XL. A plane may be turned and backed onto its hard standing by hand or by tractor and dolly; it may taxi in and turn on the hard standing (fig. 18①), or a "taxi-through" arrangement may be used (fig. 18②).

d. Alert apron. An alert apron normally is provided at the down-wind end of a runway and sometimes at both ends (figs. 13 and 19). The size of the apron depends upon the number of planes to be alerted. Normally, it should be at least 300 feet square.

e. Roads. An access road is required connecting the airdrome site with adjacent highways, railroads, or docks. Branching from the access road are service roads connecting supply areas, taxiway system, headquarters, and bivouac areas. At first the taxiways may serve as service roads to parked planes but as traffic becomes congested separate service-road loops may be required (fig. 13).

f. Facilities. Criteria and recommendations for lay-out of installations such as gasoline and ammunition supply, utilities, and technical facilities are given in chapter 22.



② *Taxi-through type.*
Figure 18. Continued.

g. Protective works. Lay-out and design of entrenchments, emplacements, protective walls, shelters, and other protective works are given in chapter 23.

58. AIRPLANE WHEEL LOADS FOR DESIGNING THICKNESS OF RUNWAYS, TAXIWAYS, HARD STANDINGS, AND APRONS. Table III gives wheel-load values for use in connection with the charts in figures 68 and 69 and with tables XXI and XXII, in estimating required thicknesses of base course and pavement. These design values represent the weight and

Table III. Wheel loads for thickness design of runways, taxiways, hard standings, and aprons (Refer to figs. 68 and 69 and tables XXI and XXII)

Type of aircraft	Wheel load (pounds)
Fighters and light bombers, such as P–38, P–39, P–40, P–47, P–51, A–20, A–24, A–36. Cargo, such as C–47, C–53, C–60.	15,000
Medium and heavy bombers, such as B–25, B–26, B–17, B–24. Cargo, such as C–45, C–46, C–54.	37,000*
Superbombers, such as B–29. Cargo, such as C–74.	60,000*

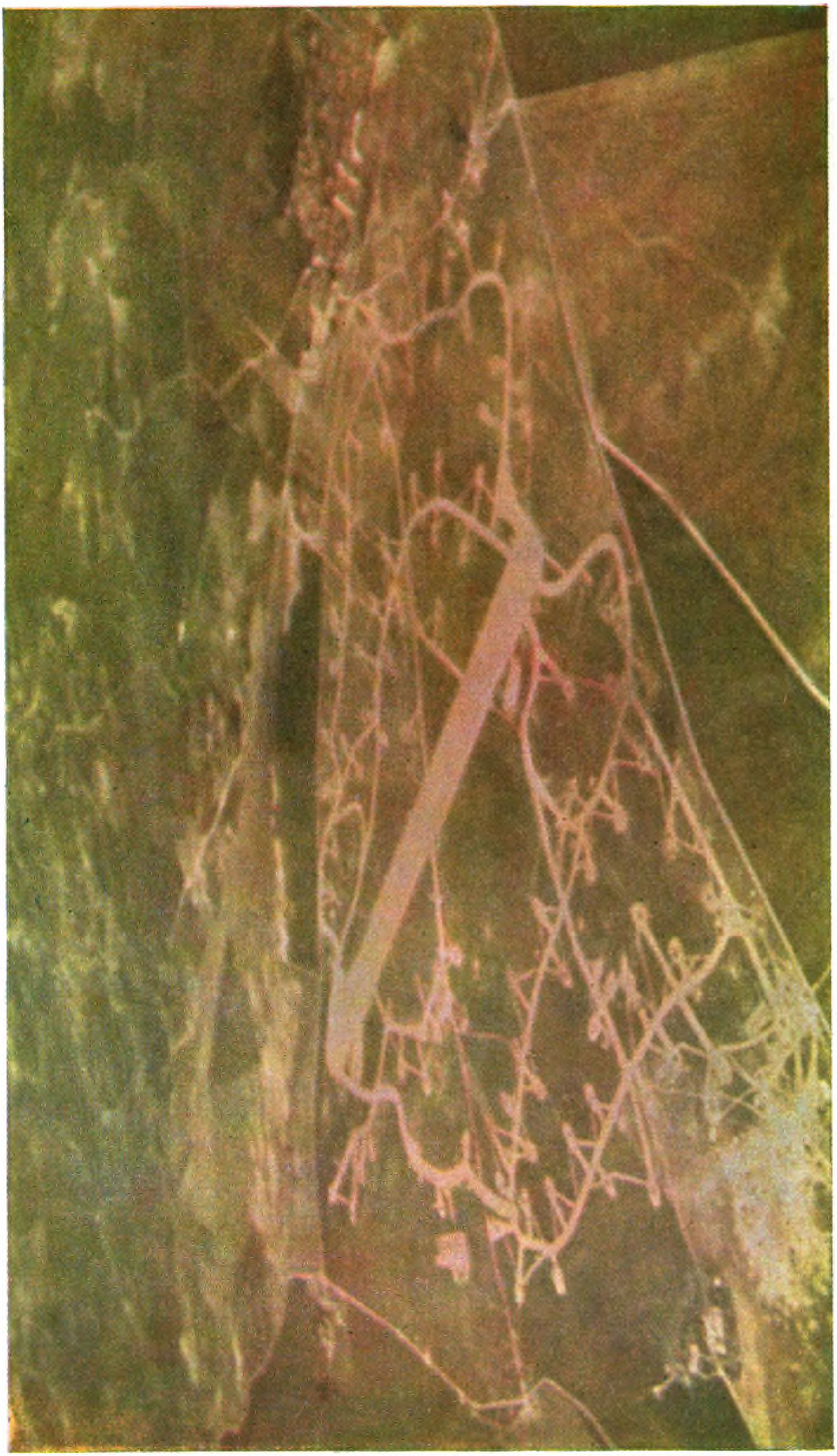
* Use for both single- and dual-wheel loadings. For design purposes dual wheels are considered as one load with one contact area.

other effects of the various planes that may be expected to use the same class of airdrome. Greater refinement or subdivision of design values is not warranted because it is not practicable to design a runway pavement for a particular model of airplane.

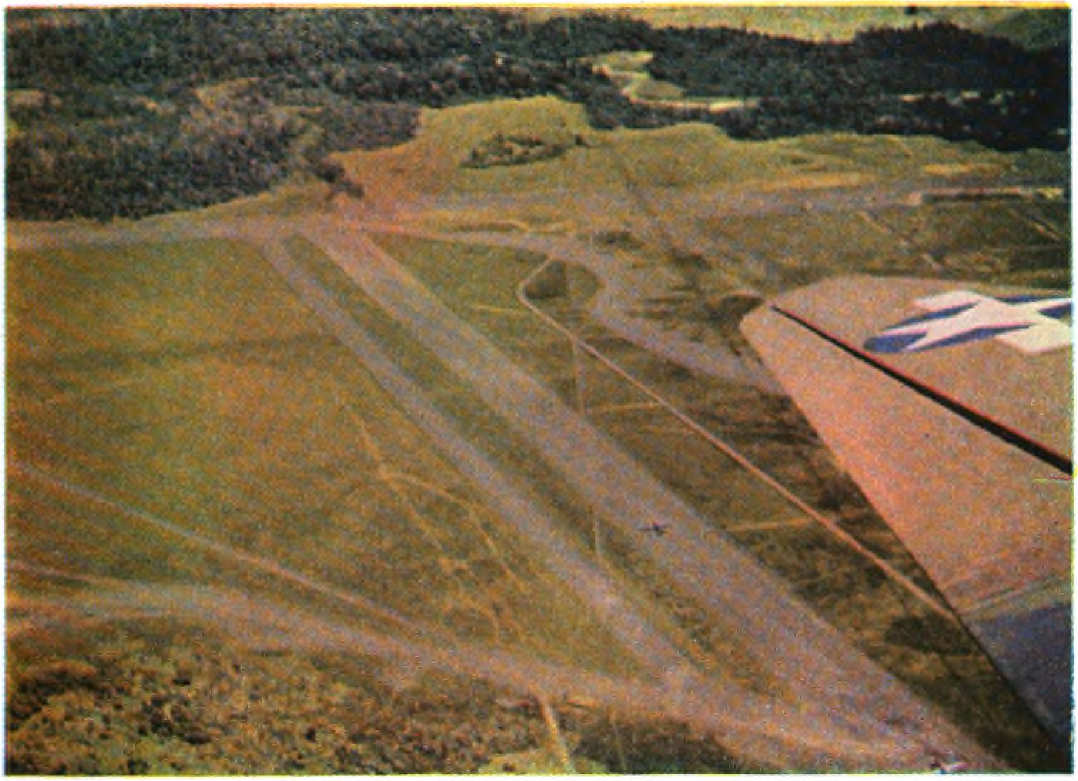
59. EXAMPLES. Figure 19 shows examples of airdromes, taxiways, hard standings, and alert aprons, as actually used in various theaters of operation.

Figure 19. *Examples of field installations.*

① **Field airdrome.**



(21) *Field airdrome.*



③ *Field airdrome (Note parallel arrangement.)*

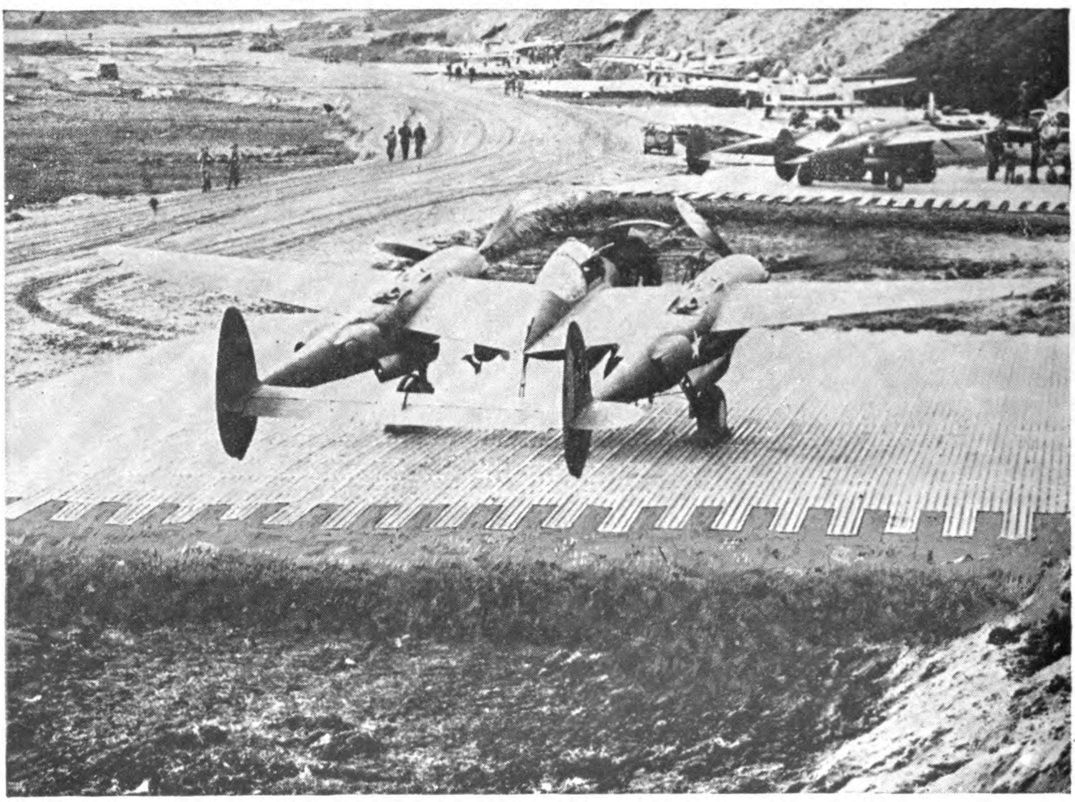
Figure 19. Continued.

④ *Fighter plane turning on taxiway from its concealed hard standing.*

⑤ *Taxiway for bombers. Note clearance.*

Figure 19. Continued.

⑥ *Temporary hard standing surfaced with steel landing mat.*



⑦ *Harding standing for medium bomber.*

Figure 19. Continued.

⑧ *Hard standings and taxiway.*

⑨ *Alert apron, bituminous-surfaced.*

Figure 19. Continued.

⑩ *Alert apron—steel landing mat surface.*

CHAPTER 8

RECONNAISSANCE AND SITE SELECTION

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60. GENERAL. a. See chapter 3, FM 5–6, for general discussion of engineer reconnaissance. Every airdrome site must be reconnoitered on the ground by an engineer officer before troops and equipment are committed to the task of construction. This assures time and effort will not be wasted at a location inherently unsuitable for air operations, or which cannot be made ready in time to serve tactical needs. Likewise, every site must be reconnoitered from the air by an experienced pilot officer to check flying characteristics, obstructions, and other operational factors.

b. Scope of reconnaissance in each case varies with the purpose, time available, and amount of knowledge at hand. Following are illustrative situations:

(1) In mobile operations advanced landing fields for fighter planes are needed well to the front but out of enemy artillery range. As the front advances, fighter planes must be moved to forward advanced landing fields. Reconnaissance of such fields is characterized by extreme urgency. It is made by parties accompanying our ground forces. In amphibious operations airdrome-reconnaissance parties follow closely the initial landing. Some of the sites will have been tentatively selected by map and aerial photograph study and aerial observation while they were still in enemy territory. If the sites were used by the enemy for air operations considerable advance knowledge may be deducted from intelligence sources. Captured airdromes often can be restored quickly for use by our fighters. However, ground reconnaissance may disclose that time and effort required to remove mines and booby traps, to repair damage caused by our bombing and shelling, and to repair the enemy's destruction before retiring, is greater than that which will provide a usable field at an undeveloped site in the same vicinity.

(2) In developing bomber airdromes during a rapid advance, sites previously used by fighters often can be utilized with some additional construction. In these cases reconnaissance is relatively simple because all characteristics and limitations of the sites are known.

(3) Reconnaissance of undeveloped areas not occupied by either the enemy or our forces must be of considerable scope. Lacking knowledge of flying conditions, weather, availability of construction materials, water supply, drainage, soils, and transportation, the reconnaissance must investigate and weigh all factors and present an accurate estimate of the situation. This estimate may be

important in shaping the tactical plan and is the basis for the general construction plan. The scope of reconnaissance of this type varies from finding a site for a single all-purpose airdrome, with auxiliary landing strips, to finding sites for several airdromes such as eventually are required for major operations in an entire region. Where such an undertaking is within fighter aircraft range of the enemy the reconnaissance must be especially directed to the initial problem of rapid construction of an advanced landing field with minimum essential facilities for serving aircraft, so fighters, and sometimes both fighters and bombers, can operate from it at the earliest moment.

(4) A special case of reconnaissance of this type is represented by the problem of providing airdromes on forward islands. Here the additional problems of moving over water, landing, building beach access roads, establishing and maintaining security, and supplying the operation must be considered along with the technical problems of airdrome construction.

61. SOURCES OF GENERAL INFORMATION. There are many sources of general information which may expedite airdrome reconnaissance and site selection in foreign territory, but such information never should be relied upon without verification by actually reconnoitering the ground. Useful reports will be on file or may be obtained by the intelligence section. Examples are:

a. Intelligence reports, special studies, and strategic studies, especially terrain reports. Information on road materials in terrain reports may be applicable to airdrome construction.

b. Soil and geologic maps compiled and published by foreign governments.

c. Summary weather reports compiled and published by governmental agencies.

d. Aeronautical reports and charts.

e. Air force weather reports.

62. RECONNAISSANCE INSTRUCTIONS. **a.** Before a search is made for sites instructions to the engineer concerning the following must be issued by the air force commander:

(1) General area in which airdrome is required.

(2) Classification of airdrome—fighter or bomber, for temporary or continuous operations—and minimum requirements as to dimensions, grades, and clearances.

(3) Air force units to be accommodated initially.

(4) Minimum aircraft service and repair facilities required initially.

(5) All special requirements, such as night flying.

(6) Probable future use of airdrome.

(7) Time available.

b. The objective of the reconnaissance is to find a site most nearly meeting all requirements, decide the general lay-out and construction plan, and determine the *minimum time* necessary to construct it. This report then is used as a basis for the tactical plan and timetable. However, when the tactical situation requires an airdrome to be completed within a certain time the construction plan is based on the available time.

63. RECONNAISSANCE PROCEDURE a. To find successively advanced landing-field sites for fighter planes as a land front advances it is desirable to prearrange for rapid reconnaissance by a special detail. Direct communication is provided among the engineer section of air force headquarters, the reconnaissance detail, and the engineer units available for construction. Usually tentative sites will have been selected on information obtained from maps, aerial photographs, reports of aerial observers, and other intelligence. As soon as a potential site or an enemy airdrome is accessible it is reconnoitered by the special detail. In the case of an undeveloped site the object is to verify the previous tentative selection and lay-out, and to estimate material, equipment, and troop requirements. In the case of captured enemy airdromes the reconnaissance must determine whether it is better to undertake rehabilitation or to select an undeveloped site. In either case estimated requirements must be communicated quickly to headquarters.

b. In friendly territory in which our aircraft already are operating the following reconnaissance procedure will save time. Select the best available map of the area specified for the general location of the airdrome. Draw a 5-mile circle around existing airdromes and shade each one. Similarly, shade all high-tension electric transmission lines and the zones 2 miles on either side. Locate and mark all known flying obstructions identified on air charts or aerial photographs. Then study the unshaded portions to find sites that have sufficient area, preferably on flat ground with good natural drainage, and unobstructed air approaches, and are accessible to routes of communication. Investigate these sites in detail by aerial and ground reconnaissance.

(1) *Aerial reconnaissance* is made jointly by the engineer officer and an experienced pilot officer. The pilot observes general flying characteristics, obstructions, and other operational factors. The engineer studies drainage, construction problems, routes of communication, and camouflage possibilities. Aerial photographs, including stereoscopic pairs, should be made of each site. Study of these gives valuable information on soil conditions (par. 100). The pilot and engineer agree on tentative sites subject to confirmation by ground reconnaissance.

(2) *Ground reconnaissance* is made by the engineer assisted by a party with selected equipment. A reconnaissance plan and report outline (par. 65) should be made in advance to avoid omission of essential observations at the site. Preparations for the reconnaissance should include gathering all information that can be obtained from sources mentioned in paragraph 61. If wind records are available, they may be analyzed by the method in table LXXVII, appendix V. While at the site all previously acquired information concerning it is checked for verification. Maps are checked for general reliability, and aerial photographs for interpretation. All additional information pertinent to the problem is gathered

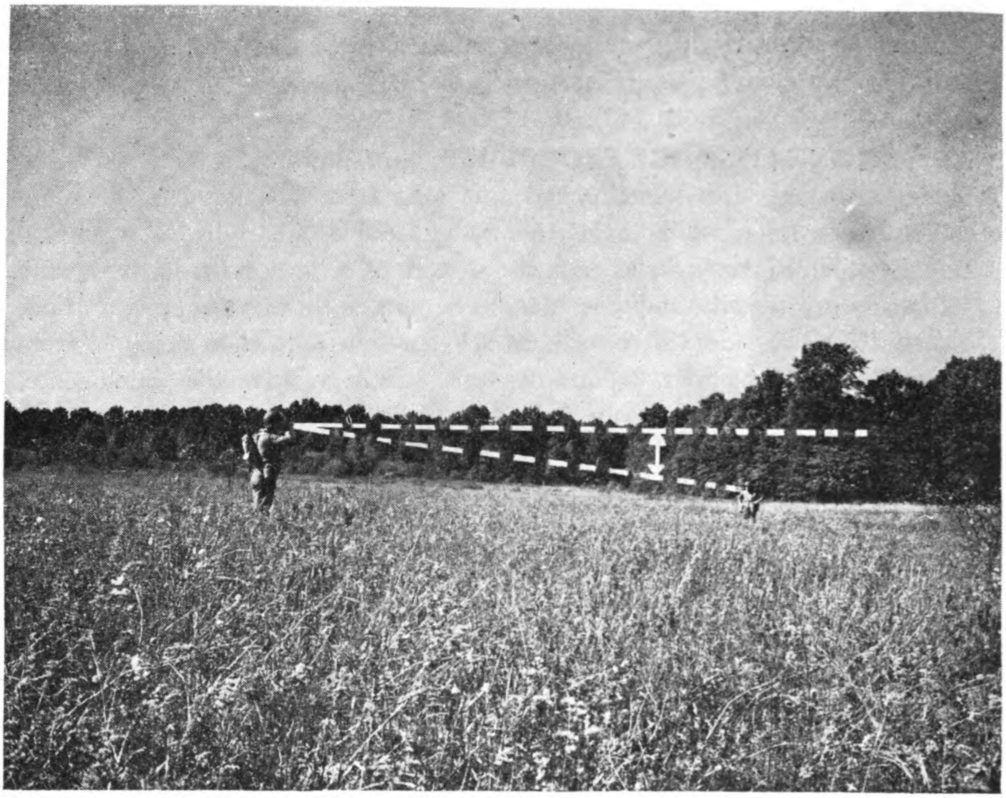

Figure 20. Ground reconnaissance—measuring ground slope.

by direct measurement (fig. 20), observation, and ground photographs. Where possible, local inhabitants are interviewed; however, their information should be carefully weighed. Several separate opinions should be obtained and replies should be checked by repeating questions in different forms. The reconnaissance report outlined in paragraph 65 is used as a check list to avoid omitting any vital data.

c. In undeveloped territory the usual procedure is to gather and study all information obtainable from natives and any available maps, aerial photographs, or documents mentioned in paragraph 61. However, these sources often are not fruitful and principal reliance must be placed on systematic aerial reconnaissance made jointly by engineer and pilot officers. Promising sites are photographed and investigated later by ground reconnaissance. Native guides often are employed to assist the ground party.

64. FACTORS TO BE CONSIDERED. Site selection usually is a compromise among tactical, operational, and engineering requirements. The engineer must visualize the maximum means of the equipment, material, and troops at his disposal, then choose a site within the designated vicinity at which usable facilities can be provided in the shortest time. Initial installation can be improved by stage construction (par. 52). Future expansion, though important, often must be subordinated to the mission of providing acceptable minimum requirements rapidly. The following factors are the important ones to be weighed in making a decision; therefore in reconnaissance they are the ones which must be covered as thoroughly as time permits.

a. Area. The site must afford sufficient area for the required number and size of landing strips and taxiways, and dispersed locations for hard standings and ground installatons. If dimensional requirements are not covered by special directive or in reconnaissance instructions, the general criteria in chapter 7 are applied in judging whether a site has sufficient area.

b. Accessibility, communications, and supply logistics. A site should be accessible by road, rail, or water. Large tonnages of imported construction materials often are required, and during operational use large quantities of gasoline and ordnance supplies are needed. The site should place a minimum burden upon supply channels in the theater of operations. Where an airdrome must be built at a site inaccessible by land or water routes, airborne aviation engineer equipment may be employed and supplied by air transport. (See ch. 5 and par. 207.)

c. Obstructions. An obstruction-free flight zone, including the entire circumferential area of the field, is preferred but, lacking this, there must be an obstruction-free approach zone at each end of the landing strip. Man-made obstructions such as towers, stacks, and pole lines often can be removed. Trees obstructing the approach and safety-clearance zones may be topped or removed. Besides physical obstructions consideration should be given to pilot reactions. There is a natural, strong objection to landing over obstacles at night even though they are below the angle of glide and well marked. An airdrome on a plateau with steep sides falling from the ends may have perfect approaches, but pilots always will land a long way in from the end. A canal, ditch, or bank at the end of a runway has the same effect. The result of these reactions is equivalent to a shortened runway.

d. Meteorological conditions. Wind, rainfall, fog, and snow effect construction and operational use of airdromes, both of which must be considered in site selection. Meteorological data usually is difficult to get but this should not lessen the attempt.

(1) Desired *wind* information includes intensity and direction of the prevailing wind; data on storm winds such as direction, intensity, duration, and frequency or season of occurrence; and local peculiarities of winds, such as down drafts, turbulence caused by nearby hills, and any pronounced differences between day and night winds.

The air force weather section may be helpful in furnishing general wind data. Information should be obtained from all available weather records, from local inhabitants, and from observations of terrain and vegetation at the site. For example, winds tend to parallel the long axes of valleys. Often there is a significant increase in the number of leaves and branches on plants and trees exposed to continuous moderate winds. Tall trees in the open exhibit a characteristic slope on the windward side. (See fig. 21.) The windward side of a hill often

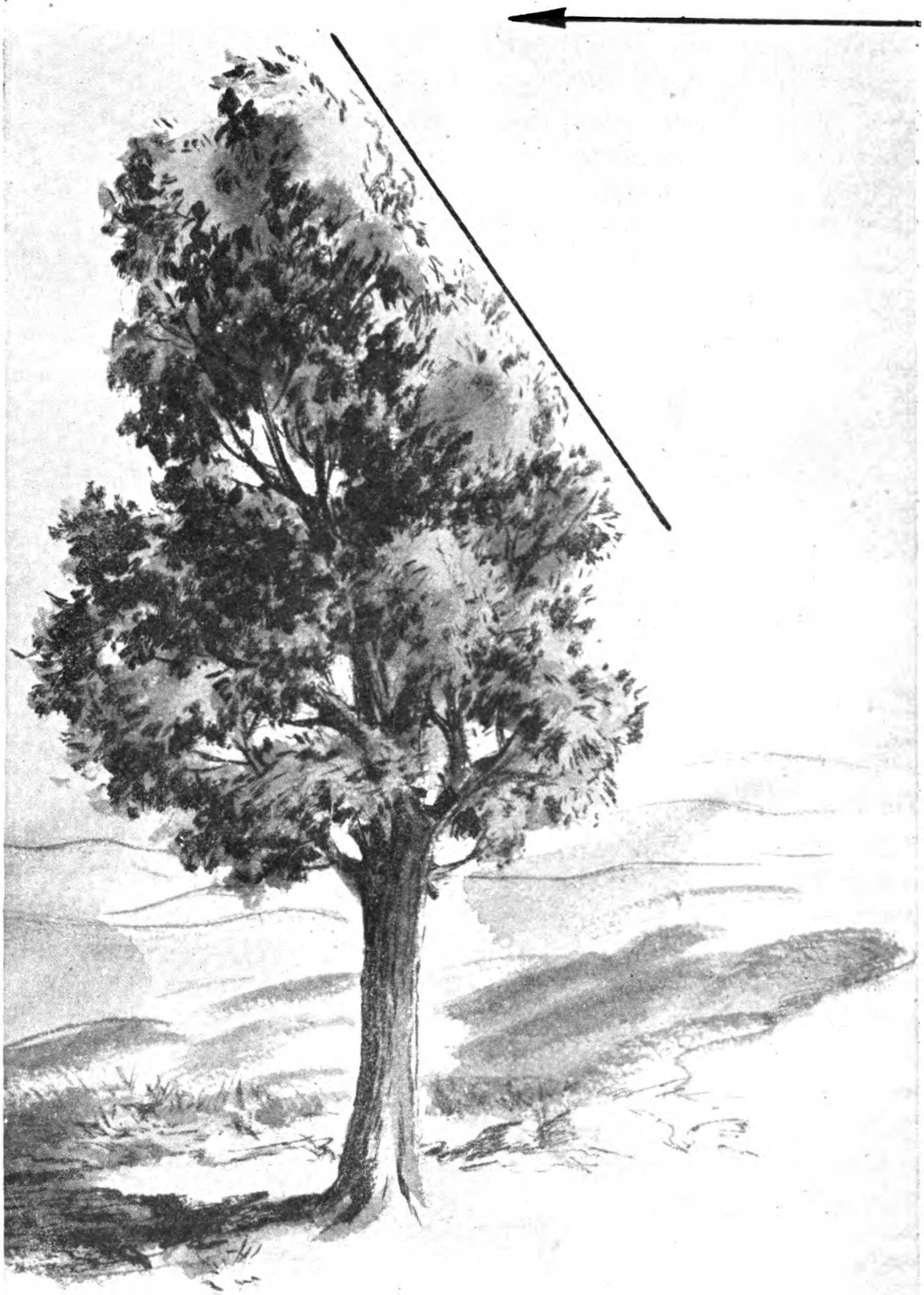

Figure 21. Characteristic shape of exposed trees indicates prevailing wind direction.

has low-growing vegetation while the leeward side has taller growth. On the lee side of every rock and topographic obstacle there is a limited zone of vertical calm in which plants frequently find shelter from destructive winds. Their presence, position, and shape are good indexes of prevailing wind direction.

(See fig. 22.) The position and orientation of sand dunes or other drifted material likewise are reliable indicators of wind direction. (See fig. 23.)

(2) Rainfall data, like wind data, must be obtained from various sources. Information should include average rainfall by months, probable date of first rains that will seriously affect construction or aircraft operation on unsurfaced landing strips, duration of the wet season, and rainfall characteristics as expressed by intensity, duration, and frequency data.

(3) Snow and frost data should be obtained in regions where they may affect construction and air operations, particularly at sites having subgrade soils susceptible to frost action (par. 95 and table V).

(4) Other factors to be investigated are temperature variations, barometric pressure variations, prevalence of dust storms, and daily or seasonal occurrence of fogs.

e. Hydrologic conditions. The hydrologic conditions to be investigated and considered include position and seasonal variation in elevation of the ground-water table, flood characteristics of streams bordering the site, and tidal variations at coastal locations. These matters are highly important. Unless care

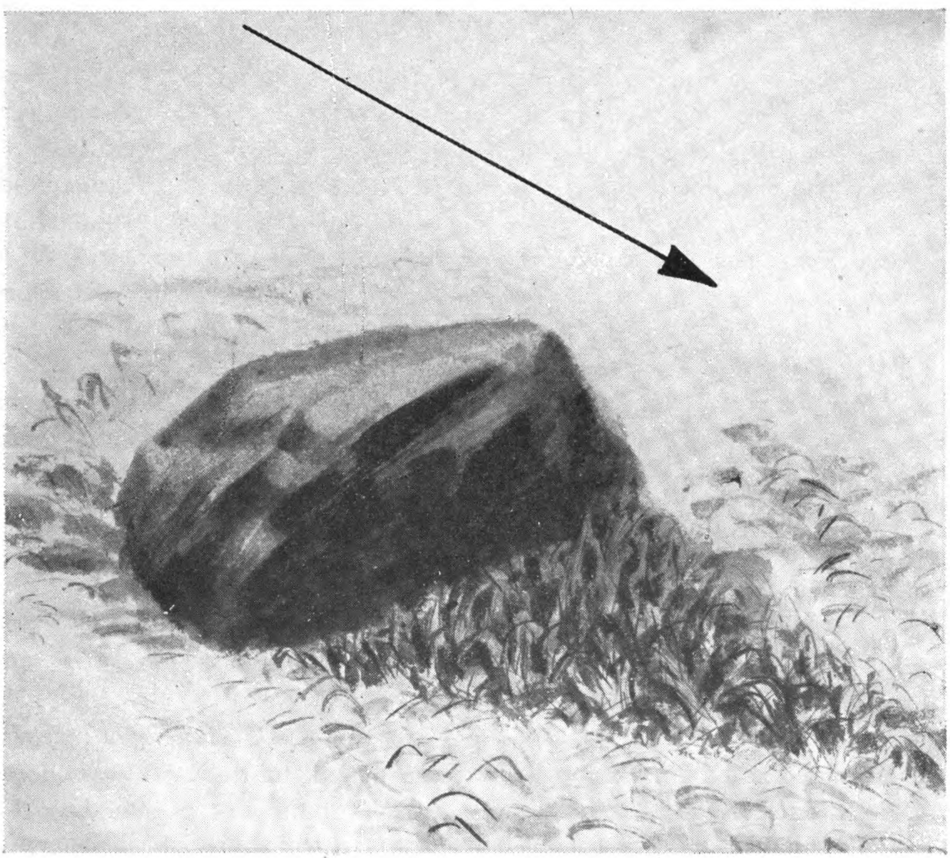

Figure 22. Wind direction indicated by shape and position of vegetation behind rock.

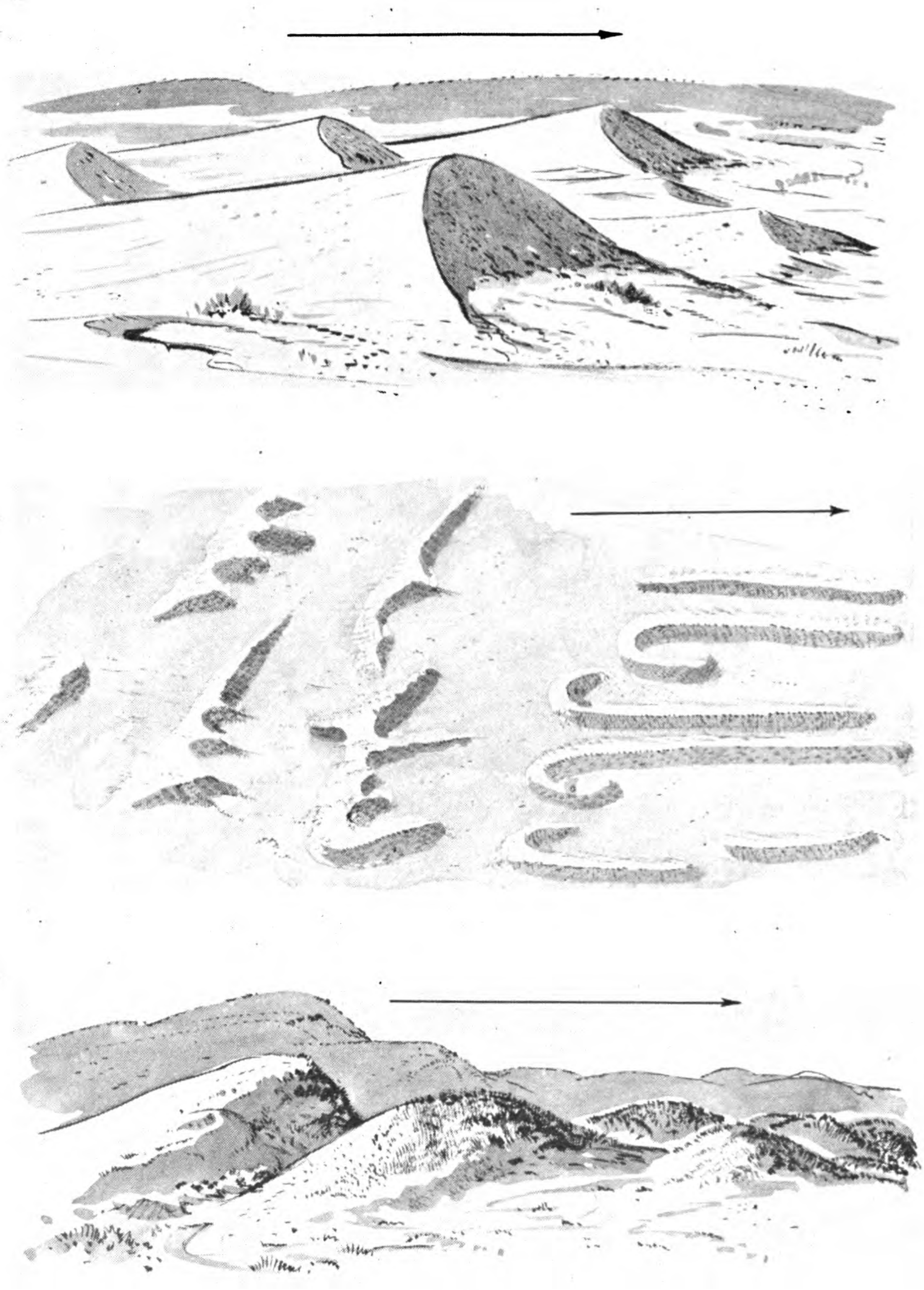

Figure 23. Wind direction indicated by shape and orientation of dunes and other aeolian deposits.

is taken, reconnaissance during the dry season may be misleading. Vegetation sometimes discloses evidence of seasonal seepage or rise in the ground-water table. For example, reeds, sedges, cottonwoods, and willows thrive where seepage occurs even though the seepage is seasonal.

f. Topography. A site with favorable topography is one located on high ground, with sufficient slope for natural surface drainage, and a reasonably smooth surface requiring little grading. Where the choice is between a rough, well-drained site and a level wet one, it is necessary to estimate and compare the time and effort required to grade the rough site with those required to drain and strengthen the wet one. (See ch. 21 for estimates.)

g. Clearing and grubbing. An estimate is made of the clearing and grubbing required. (See ch. 21.)

h. Soil characteristics and quality of subgrade. The character of the soil on the site determines whether or not a runway must be constructed before planes can operate. Where a runway is required the quality of the soil determines how thick the base course must be. The same is true for taxiways, hard standings, aprons, and roads. Base-course thickness is one of the critical decisions to be made for any site. To evaluate conditions correctly it is necessary to examine soils carefully and apply practical soil technology. (See chs. 11, 12, 14, and 15.)

i. Availability of local materials. Where a base course is required for the runway, taxiways, hard standings, and roads, the quantity of natural material necessary is a major item. Reconnaissance must include exploration for sources nearest the site that will yield material adequate in quality and quantity. For discussion of suitable natural materials and design of base course, see chapters 12 and 15. The use of steel landing mats should be considered in evaluating this problem. (See ch. 16.)

j. Water supply. Large quantities of water generally are required in both construction and operation. Water for personnel also must be provided. (See ch. 21 and table XLVIII.)

k. Prevailing weather during construction. Weather must be considered, especially the probable delaying effects of rain, snow, and frost during construction.

l. Camouflage. A desirable site is one that avoids indentifying landmarks and affords natural concealment for parked aircraft, dumps, bivouacs, and other installations at dispersed locations. (See par. 188.)

m. Defense and protective construction. Terrain advantages for defense must be weighed and balanced against other factors. Terrain favorable for defense provides observation, fields of fire, concealment, obstacles, and routes of communication. Natural obstructions to landing areas adjacent to the airdrome assist defense. Protective construction is simpler if natural cover can be converted to shelters with little effort. (See par. 185.)

65. SITE SELECTION AND RECONNAISSANCE REPORT. **a.** Keeping in mind barest essentials, and limitations of troops and equipment, the reconnaissance information for each site is analyzed to formulate the most feasible plan for construction in the least time or within the time specified.

b. The following must be decided and recorded on sketch plans:

(1) Location and direction of landing strips.

(2) General locations of first taxiway loop and sufficient hard standings for initial air operations.

(3) Drainage plan.

(4) Construction required for initial air operations on landing strips, taxiways, hard standings, aprons, and roads. This decision must consider soil conditions and expected weather and their probable effect upon air operations. The decision usually involves one of the following:

(*a*) Cleared, graded, drained, and compacted earth.

(*b*) Compacted earth with dust palliative.

(*c*) Steel landing mat on compacted earth.

(*d*) Compacted base course of local natural material.

(*e*) Steel landing mat on a base course of local natural material if subgrade soil is of low stability. (In an emergency steel landing mat often will serve for a short time on soil of low stability.)

(*f*) Base course of local natural material with a dust palliative or bituminous surface treatment.

(5) Water-supply scheme for construction needs.

(6) Location of access road and initial service roads.

(7) Location and facilities required for camps, including water supply for personnel.

(8) Location of fuel, ammunition, and supply dumps.

(9) Location and kind of defense installations.

(10) Location of suitable mulching material for dust palliative.

(11) Other operational, technical, or special facilities specified in the reconnaissance instructions.

(12) Priorities for the various items, and sequence of construction operations.

c. The estimate of materials and time required must consider the items listed below. (See ch. 21, especially par. 169, for data and methods of making preliminary estimates.)

(1) Moving to site and constructing access roads or temporary dock if required.

(2) Establishing camp and security.

(3) Clearing and grubbing landing-strip area, initial taxiways, first hard standings.

(4) Draining and grading items in (3) above.

(5) Runway and taxiway construction, and surfacing hard standings and roads.

(6) Preparation of dumps and other installations.

d. The reconnaissance report with recommended site selection is submitted by the engineer officer to the air force commander through the air force engineer. The outline below, expanded as necessary or with inappropriate items omitted, is used as a guide for preparing the report and recommendation.

OUTLINE OF AIRDROME SITE RECONNAISSANCE REPORT

Reference and reconnaissance instructions number:
Purpose of reconnaissance:
Date, time, and period of reconnaissance:
Date and time of report:

a. Location and description of site.
- (1) Latitude and longitude, grid coordinates and map reference, or distance and bearing to nearest mapped town or village.
- (2) Elevation above sea level.
- (3) Natural condition of surface.
- (4) General slope of ground—direction and gradient.
- (5) Obstructions.
- (6) Vegetation.
- (7) Possibilities for dispersion and concealment.
- (8) Defensive strength.
- (9) Accommodations and facilities in nearby communities.
- (10) Camp sites.

b. Meteorological data.
- (1) Velocity ranges, duration, and directions of prevailing and storm winds.
- (2) Rainfall—seasonal rainfall, especially probable influence on construction and air operations on landing strips; average rainfall by month; rainstorm frequency-intensity duration data.
- (3) Snowfall—amount and time of occurrence.
- (4) Frost—season, depth of penetration.
- (5) Temperatures.
- (6) Barometric pressures.
- (7) Dust or other storms.
- (8) Fogs—daily or seasonal.

c. Hydrologic data.
- (1) Ground-water table—position and variation.
- (2) Flood characteristics of nearby streams.
- (3) Tidal variations.

d. Soil data. (Take representative samples of soils.)
- (1) Engineering classifications and characteristics of soils on proposed landing-strip areas, especially drainage characteristics, frost-action tendency, shrinkage and expansion characteristics.
- (2) Rock outcropping in landing-strip area.

e. Local resources.
- (1) Base-course materials—character of and quantities in existing pits and quarries, mine dumps, or undeveloped deposits. Take representative samples. Note locations of sources, roads required, method of recovery, plant for processing.
- (2) Timber.
- (3) Construction equipment and repair shops.
- (4) Native labor.
- (5) Building materials—lumber, hardware, paint, and so on.

f. Water supply.
Amount, quality, required treatment, distance from site, and elevation in relation to site.

g. Access and communications.
Existing roads, railroads, and docking facilities, their capacities and limitations.

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h. Utilities.

Existing electric-power, telegraph, and telephone lines.

i. Sketch plan of site showing:

(1) Location name.
(2) Map sheet, grid reference, and bearings on fixed points.
(3) Scale, date, and name of sketcher.
(4) North arrow.
(5) Prevailing wind and storm wind arrows.
(6) Obstructions to flying.
(7) Natural drainage lines, streams, swamps, and marshes.
(8) Outline and dimensions of usable area.
(9) Approximate contours or average slopes in usable area.
(10) Existing buildings, roads, railroads, and electric power, telephone, and telegraph lines.
(11) Sources of natural materials for base course.
(12) Proposed lay-out for *initial* construction.
  (*a*) Landing strip and runway—show dimensioned plan, longitudinal center-line profile, and typical cross section.
  (*b*) Angle of glide for a distance of 2 miles from ends of landing strip.
  (*c*) Taxiways.
  (*d*) Drainage plan.
  (*e*) Dispersed hard standings.
  (*f*) Roads—access and service.
  (*g*) Camp areas.
  (*h*) Dumps—fuel, ammunition, and supply.
  (*i*) Defense installations.
(13) Possible future extensions or additions—landing strips, runways, taxiways, hard standings, and other facilities.

j. Estimate of troops, equipment, materials, and time to provide specified minimum initial facilities.

k. Recommendation.

l. Signature, rank, and organization.

m. Annexes—maps, photographs, sketches.

CHAPTER 9

ADVANCED LANDING FIELDS

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66. PURPOSE. The need for advanced landing fields becomes urgent as our troops move rapidly ahead or, in some cases, on islands or territory behind the enemy. Time is the all-important factor and this type field may serve its purpose if available for only a few days. As the forward area becomes the rear area, an advanced landing field can be improved for our medium and heavy bombers but initially it serves our fighter and transport planes.

67. REQUIREMENTS. a. Speed and simplicity are the essence of advanced landing field construction. Three essential factors govern speed of construction: reconnaissance to find a site at which little work is needed; getting troops, equipment, and material to the site quickly; and continuous work until the field is in operation. Simplicity means undertaking no more work than is necessary for immediate air operations.

b. Dimensional and lay-out criteria for advanced landing fields are given in chapter 7. However, military necessity often requires deviation from recommended minimum standards, especially for the more temporary fields. The common deviations are steeper angle of glide and greater angular difference between direction of landing strip and prevailing wind direction.

c. The minimum facilities to be provided at an advanced landing field usually are:

(1) One landing strip with dispersed hard standings and connecting taxiways, all cleared, drained, and graded. These must be surfaced if used for operations in wet weather (fig. 19⑥).

(2) An access road, unless air transport is used.

(3) Dumps for supplies, ammunition, and gasoline drums.

(4) Service roads from dumps to taxiways and hard standings.

(5) Drinking water supply.

d. To permit rapid construction a site must be fairly clear of trees and dense growth, flat enough to require little grading, and slightly sloped, so that effective drainage can be provided by simple open ditches.

e. Because of their temporary nature and susceptibility to enemy raids provision must be made for continuous maintenance and repair (ch. 24).

68. RECONNAISSANCE AND LAY-OUT. **a.** The reconnaissance procedure for advanced landing fields, generally, is as described in chapter 8, with special emphasis on detailed study of aerial photographs, maps, and intelligence reports. All possible information should be compiled in advance of ground reconnaissance, sometimes even to the point of a preliminary lay-out. Ground reconnaissance upon arrival at the site must be a rapid but accurate appraisal of conditions, or verification of previously acquired information.

b. A practical test for stability and wheel-supporting capacity of an earth surface may be made by running a car or truck back and forth over a short distance six times in the same tracks. If the resulting depression, measured at the midlength of the track, is no more than about one-half inch, and if no further deepening results with additional running in the same tracks, the surface is satisfactory.

c. Lay-out is decided during the reconnaissance. Detailed surveys and plans are not made (fig. 24①). Usually a center-line profile and a few transverse profiles are taken from which the grade line is established and the drainage scheme decided. (See chs. 10 and 13.)

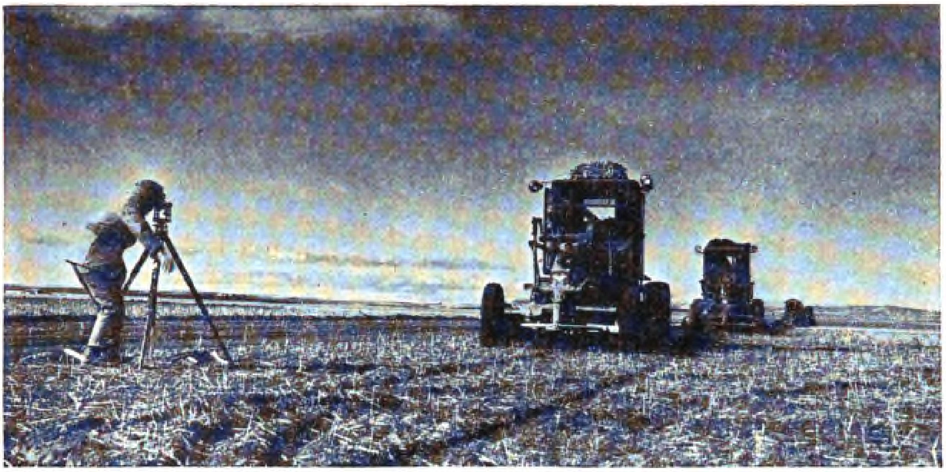
d. If a base course is required, the reconnaissance must include location of suitable materials and decision as to the thickness and method of construction. (See chs. 11, 12, and 15.)

69. HASTY ESTIMATES. Quantities of work to be done are estimated from the plans formulated during reconnaissance. These quantities are the basis for estimating either the equipment and troops required to meet a specified completion date or the time required to do the job with the troops and equipment on hand. (See ch. 21 for methods of estimating, especially par. 169.)

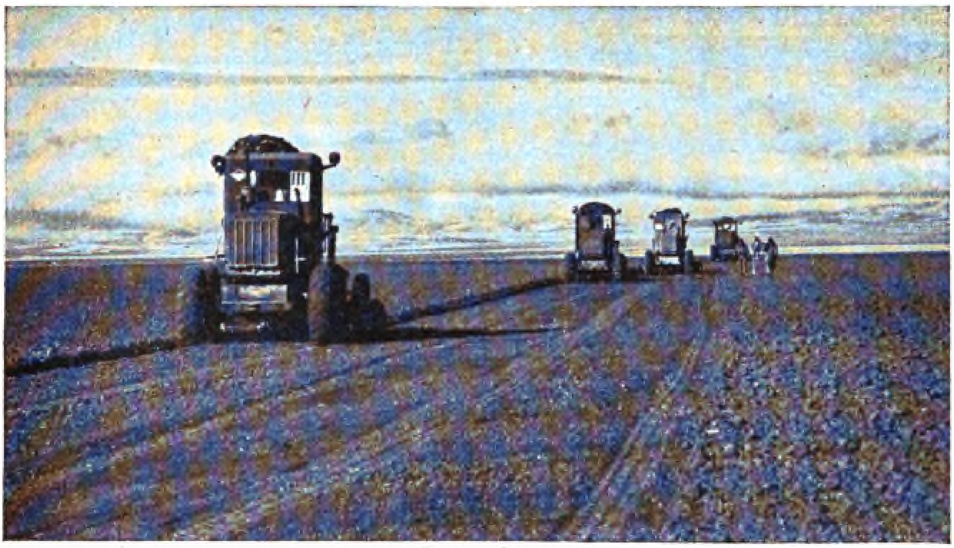
70. DRY-WEATHER EARTH FIELDS (fig. 24). **a. Soil.** The character of soil on the landing strip is the primary factor. Any soil is satisfactory if it can be stabilized easily and maintained in a firm condition suitable for plane operation. A well-graded soil containing coarse and fine particles is desirable because it can be stabilized readily by sprinkling and compaction. With good surface drainage it does not lose stability quickly in ordinary rains. Fine-grained soils are less desirable but will serve if they can be compacted. They lose stability quickly under rain, and during dry weather some types, such as silts with little cohesion, pulverize rapidly under traffic. Unsatisfactory soils are loose sand, cohesionless silt, and loose gravel. Often these can be made satisfactory by stabilizing processes discussed in paragraph 128, but considerable time is required for construction. Usually, laying a steel landing mat (ch. 16) is the quickest way of preparing such sites (fig. 26). (For complete discussion of soil classification and characteristics see ch. 11.)

b. Construction (fig. 24). The usual procedure consists of clearing and grading, disking, sprinkling, and compacting. See chapter 13 for detailed

Figure 24. Constructing compacted earth dry-weather advanced landing field.



① *Start of work.*



② *Grading.*

③ *Compacting with roller and trucks. Note corner marker of white stone rolled into surface.*

explanation of these processes. Grading is limited to providing a longitudinal profile satisfactory for planes and a cross section that will drain the surface. Stones larger than about 2-inch diameter that are not embedded firmly in the surface must be removed from the landing strip. Slopes are difficult to judge by eye and in doubtful cases an engineer's level should be used. An ordinary clinometer is not sufficiently accurate. A practical test for smoothness of the surface may be made by driving a car over it at 20 and at 50 miles per hour. If there is no undue jarring or bumping, the surface is satisfactory.

c. Maintenance. Earth surfaces require constant maintenance. The principal problems are dust from loosening of the surface and mud from rainstorms (figs. 107 and 25). To settle dust water-sprinkling and rolling are employed. Dust palliatives, discussed in chapter 17, also may be used. The best protection against mud is positive surface drainage and outfall discharge of collected surface water. (See ch. 24 for more detailed discussion of maintenance and repair procedures.)

71. ALL-WEATHER FIELDS. a. Drainage usually is the first and most important consideration for an all-weather field, both to preserve the strength of subgrade and base (par. 96) and to minimize the hazard to plane operations of standing surface water (fig. 25). Provision must be made for positive disposal of surface water by shaping the cross section to shed water to the sides (fig. 16). Open channels along the sides of the landing strip are provided to receive the surface water and carry it to a natural drainage channel or an outfall ditch away from the site (figs. 49 and 89). Every landing strip should be virtually an island surrounded by drainage channels carrying water away. (For design of drainage systems see ch. 13.)
Wherever water may flow onto a site from adjoining ground it is necessary to construct intercepting ditches or dikes to collect and divert it from the landing strip (par. 117a). The ground-water level should be at least 2 feet below the low point of the subgrade. If the advanced landing field later is developed into a field airdrome for continuous operation, the subgrade should be 4 feet above ground-water level unless the soil is granular and unaffected by water. Where ground water is a consideration and the subgrade soil will respond to subdrainage (table V) deep open ditches should be dug along the sides of the landing strip to lower and control the water level. Water collected by these side subdrains should be discharged through an outfall. When practicable, explosives should be used freely to permit rapid excavation of the side ditches and outfall.

b. A steel landing mat usually is the fastest means of providing a surface for all-weather operations. It works well on subgrades or bases such as sand that do not soften appreciably when wet (fig. 26). In an emergency it can be used for temporary operations on soils of low stability, but constant maintenance is required to keep the runway usable. If air operations must continue under such circumstances, a base course must be provided. (See par. 131 for design of the base.)

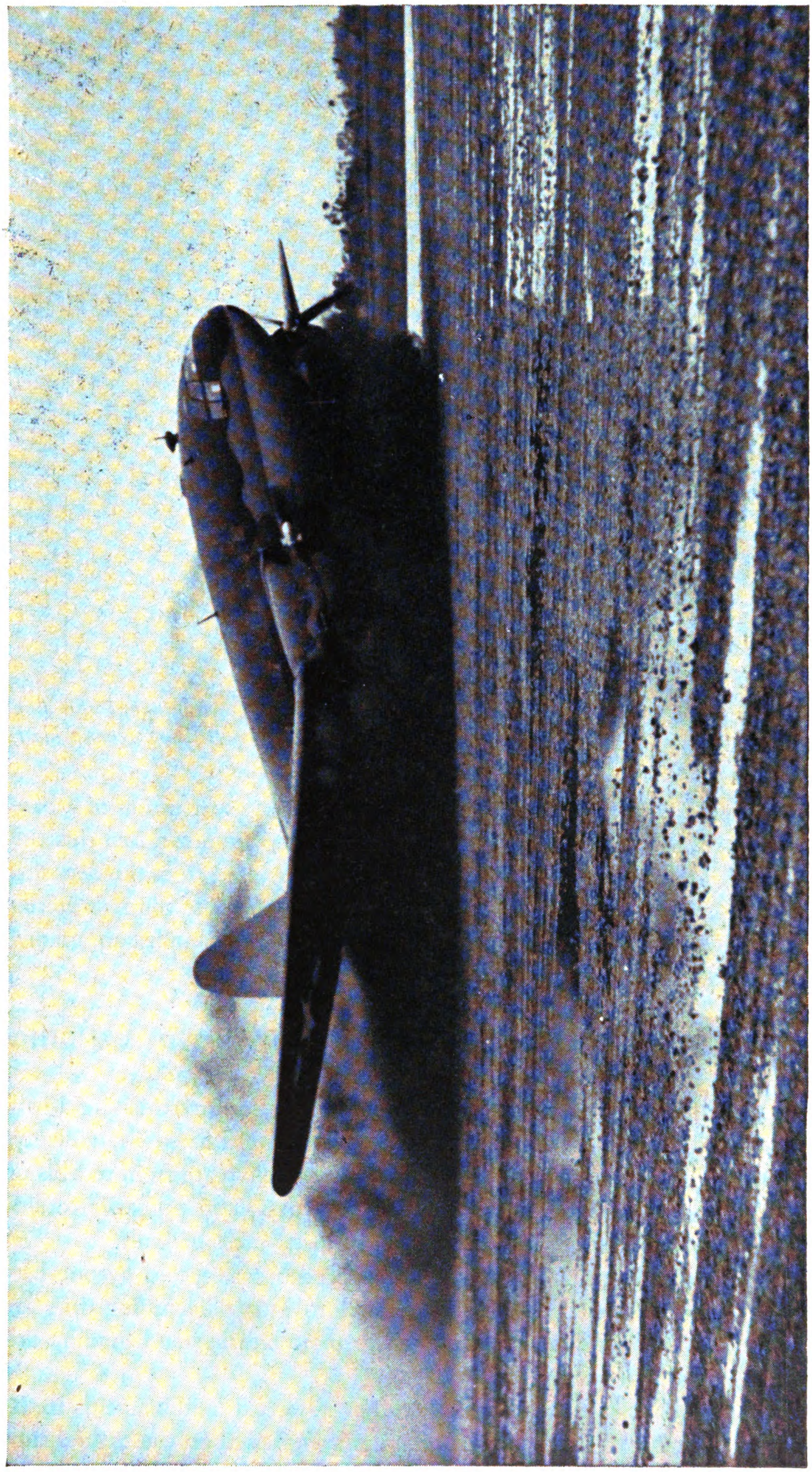


Figure 25. Surface water and mud are serious hazard to aircraft operation.

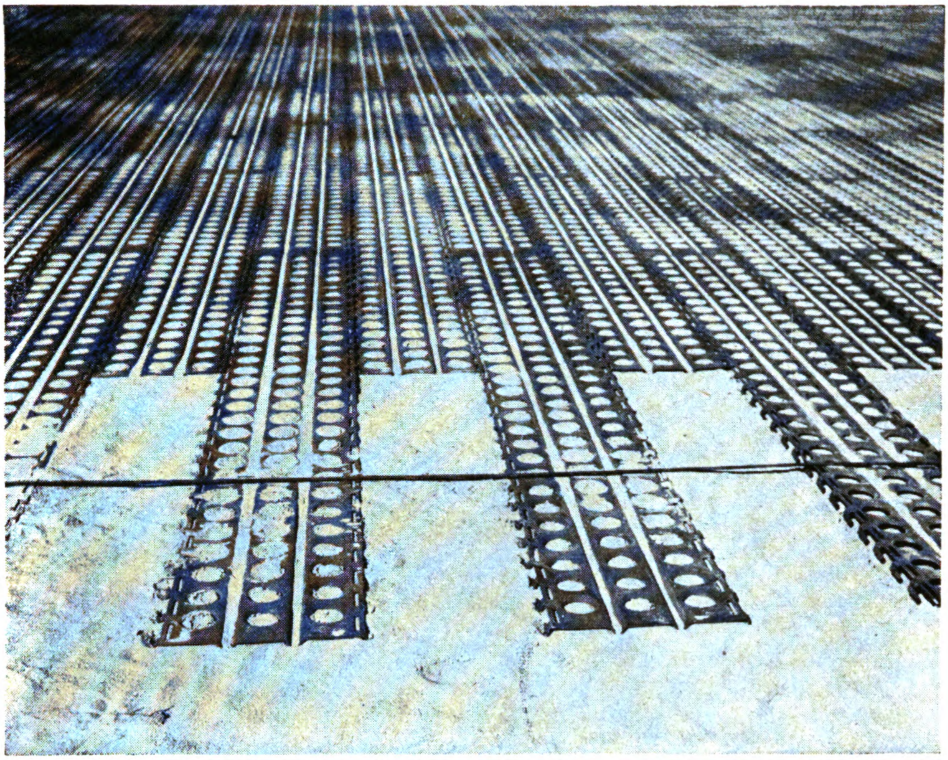


Figure 26. Steel landing mat works well on beach sand; however, for continuous operation sand should be treated (ch. 16) to prevent its displacement by propeller and exhaust blast.

c. Local natural materials often can be used for rapid construction of a base course for all-weather operations. To meet construction time requirements the materials must be relatively near the site and easily recovered from the deposits. To serve without a steel landing mat or a pavement, the base-course material must be a type that compacts readily into a stable mass. Examples are graded gravel containing some natural binder, coral, and sand-clay.

72. TIME REQUIRED TO CONSTRUCT ADVANCED LANDING FIELDS.

Caution: The following statements of time cannot be used for estimating a particular job. Each project must be reconnoitered and estimated individually. See paragraph 69 and chapter 21. The figures given below are from records of aviation engineer units in various theaters and are presented primarily to emphasize the speed with which advanced landing fields must be built.

a. Dry-weather advanced landing fields have been constructed by one battalion at favorable sites in flat terrain in from 1 to 3 days, including time for reconnaissance. At less favorable sites, where more clearing and grading are required, the time varies from 3 to 10 days.

b. One battalion has constructed all-weather advanced landing fields in 10 to 21 days. On most of them steel landing mats were used on the natural subgrade; on others base courses of local natural materials were used without surface treatment, or surfaced with steel landing mat or bituminous treatment.

c. Captured enemy airdromes have been restored for use as advanced landing fields in 1 to 3 days depending upon the amount of drainage and the number of mines and booby traps encountered.

73. AIR OPERATIONS AT ADVANCED LANDING FIELDS. Engineer troops frequently must assist air operations at advanced landing fields. To do so they must be familiar with runway marking procedure (par. 178) and signals for maneuvering planes on the ground (table XLI, app. II), control tower operations and signals (table XLII, app. II), flight patterns, and servicing of aircraft.

CHAPTER 10

PLANNING FIELD AIRDROMES

74. SCOPE. This chapter discusses various phases of planning by the construction unit designated to build a field airdrome at a site already selected. It is a summary based upon reported experience of aviation engineer units in the various theaters. Some points are applicable in some degree to every situation, but not all of them are applicable to all situations.

75. TYPICAL QUANTITIES INVOLVED IN CONSTRUCTING FIELD AIRDROME. Table IV gives a summary of typical work quantities for a field airdrome for the purpose of indicating the total amount of work that may be required, as well as the proportionate amounts for runway, taxiways, hard standings, and apron.

76. IMPORTANCE OF PLANNING. Because a field airdrome ordinarily is a large construction project, good planning is necessary to guard against costly omissions and mistakes and to assure early and correct decision concerning the main parts of the work. Construction then can be pushed without waste or duplication of effort, details being worked out as construction proceeds. Extent of planning and design is governed by time available, mission, and nature of the site. Planning always is necessary regardless of time limitations. Engineering designs should be simple and predicated upon sound principles. Overdesign is wasteful and underdesign may be disastrous. Both are to be avoided.

77. ADVANCE PREPARATIONS. The approved preliminary plan and reconnaissance report (par. 65) are the general guides for detailed plans. Additional reconnaissance and study of the latest available aerial photographs by the commander of the constructing troops generally is advisable for planning the movement to the site and establishment of the unit. Detailed construction plans require survey information. If practicable, survey parties should be sent ahead to get sufficient detailed information, so that equipment can be put to work immediately upon arrival. The air force engineer acts to acquire the land if such action is necessary.

78. SCOPE OF PLANS. The scope of plans for constructing an airdrome should include the following:

TABLE IV. *Typical quantities involved in constructing a field airdrome.*

Operation	Landing strip 6,000 by 300 ft.	Runaway and shoulders Runway 5,000 by 150 ft., surface treated base. Two shoulders, each 5,000 by 50 ft.		Taxiways Two, each 5,000 ft. by 30 ft., surface treated base. Two shoulders each 10 ft. wide Cleared area 150 ft. wide.	Hard standings Twenty-five, each 50 by 50 ft., surface treated base. Cleared area, 100 by 100 ft.	Alert apron 300 ft square, surface treated base	Totals
		Runway	Shoulders				
Clearing and grubbing	41.3 acres	(Included in	landing strip)	34.5 acres	5.8 acres	2.1 acres	83.7 acres
Grading and draining	200,000 sq. yd.[1]	(Included in	landing strip)	27,780 sq. yd.[1]	1,120 sq. yd.[1]	10,000 sq. yd.[1]	238,900 sq. yd.[1]
Base course		18,520 cu. yd. (loose)[2]	8,110 cu. yd. (loose)[3]	7,410 cu. yd. (loose)[2]	1,550 cu. yd. (loose)[2]	2,230 cu. yd. (loose)[2]	37,820 cu. yd. (loose)
Bituminous surface treatment:		83,340 sq. yd.	....	33,340 sq. yd.	6,950 sq. yd.	10,000 sq. yd.	133,630 sq. yd.
Prime coat, 0.2 gal. bitumen per sq. yd.		16,670 gal.	....	6,670 gal.	1,380 gal.	2,000 gal.	26,720 gal.
Binder coat, 0.4 gal. bitumen per sq. yd.		33,340 gal.	....	13,340 gal.	2,780 gal.	4,000 gal.	53,460 gal.
Cover aggregate, binder coat, 40 lbs. per sq. yd.		1,670 tons	....	670 tons	140 tons	200 tons	2,680 tons
Seal coat, 0.2 gal. bitumen per sq. yd.		16,670 gal.	....	6,670 gal.	1,380 gal.	2,000 gal.	26,720 gal.
Cover aggregate, seal coat, 20 lbs. per sq. yd.		835 tons	....	335 tons	70 tons	100 tons	1,340 tons
Substituting a pierced plank surface for the bituminous treatment shown above quantities of pierced plank would be as follows:							
Area to be covered (same as surface treatment)		750,000 sq. ft.	....	300,000 sq. t.	62,500 sq. ft.	90,000 sq. ft.	1,202,500 sq. ft.
No. of pierced plank panels required		60,000	....	24,000	5,000	7,200	96,200
No. bundles of pierced plank required		2,000	....	800	167	240	3,207
Weight of pierced plank mat		1,928 tons	....	771.4 tons	161 tons	231.4 tons	3,091.8 tons

[1] Size of graded area is shown in sq. yd. Volume of earthwork depends on relation of grade line to ground line. Records from the field frequently show 50,000 to 100,000 cubic yards of earthwork; however, at some sites it may be less than 50,000 cubic yards, and at others greatly in excess of 100,000 cubic yards.

[2] 6 inches compacted gravel, 8 inches loose spread.

[3] 4 inches compacted gravel, 5¼ inches loose spread.

a. Supply. Where the site is remote special arrangements are made for supplies. Special supplies needed initially and *extra spare parts* should be taken with the unit. Logistical data for estimating requirements are given in appendix IV.

b. Moving to the site. (1) Overland movements normally are by motor or rail, or both. Instructions concerning them usually are covered by the standing operating procedure of the unit. However, modifications often will be required to suit local circumstances. For example, to reach the site an access road or a bridge may be required. Provision for all such advance requirements must be made so that the heavy equipment can be moved in (par. 207).
(2) Water movements must be planned with meticulous care. Where equipment is divided among several vessels the most essential items, such as tractor-dozers, should be dispersed among them to prevent total loss by enemy action. The plan for unloading is especially important because special handling equipment may have to be taken. Having decided the unloading plan for each vessel, the order of loading is the reverse. (See par. 207.)
(3) Movement by air is governed by the nature of the cargo and the characteristics of the cargo planes. Heavy equipment may be transported by air if disassembled. (See par. 207.)

c. Security and defense. The unit commander is responsible for providing for the security of his troops at all times. Plans for security must cover movement to and operations at the site. (For detailed discussion of security and defense, see pars. 185 and 186.)

d. Establishing the unit. This includes designating and preparing a headquarters, bivouac area, motor and equipment park, water-supply point, and supply dump. Dispersion and camouflage discipline must be observed.

e. Detailed construction plans. These are worked out as construction proceeds. Surveys and design are pushed so that plans are sufficiently ahead of construction to assure proper direction and control of work.

79. SURVEYS FOR CONSTRUCTION PLANS. a. Aerial survey. (1) General requirements for an aerial survey are:

(*a*) An aerial mosaic covering the region within about 1½ miles of the site.

(*b*) Oblique photographs from the four points of the compass, taken from 3,000 feet at a horizontal distance of about 1 mile.

(*c*) Vertical stereoscopic pairs at a scale of about 1:4,800, to cover the length of the landing strip.

(2) Aerial photographs are a record of original conditions, useful in camouflage work; color photographs should be used if available. For interpretation of aerial photographs see paragraph 100, also FM 21–25 and TM 5–246. For use of aerial photographs in preparing maps see TM 5–230 and 5–240.

b. Ground survey (fig. 27). (1) The preliminary center line of the landing strip is established approximately in the position shown on the approved preliminary lay-out (par. 65). Levels then are taken of the ground surface on

Figure 27. Survey crew establishing preliminary center line.

Figure 28. Soil survey. Sinking test hole with auger. Soil is classified, data is recorded on profile sheets (fig. 29), and samples are saved.

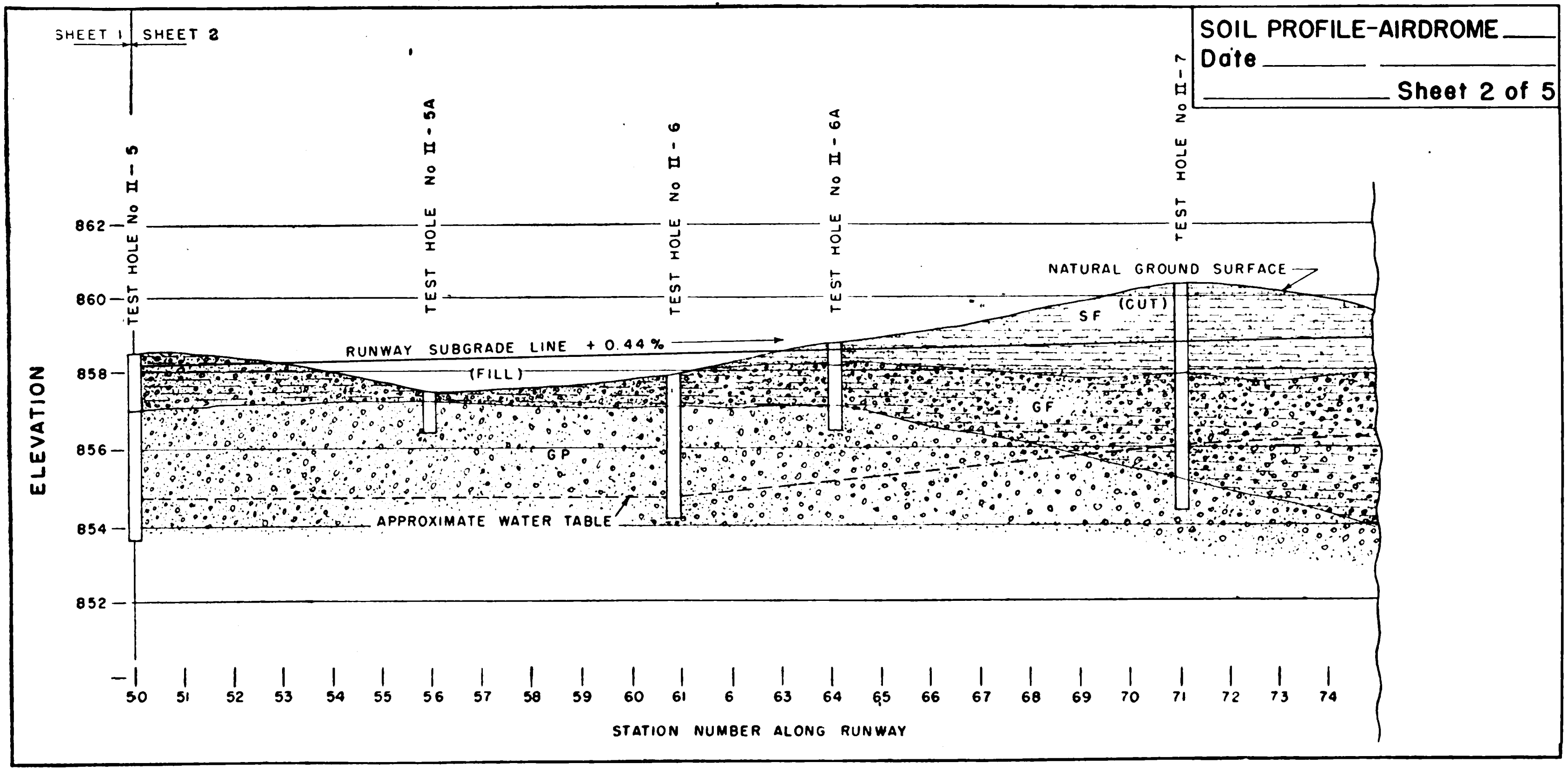
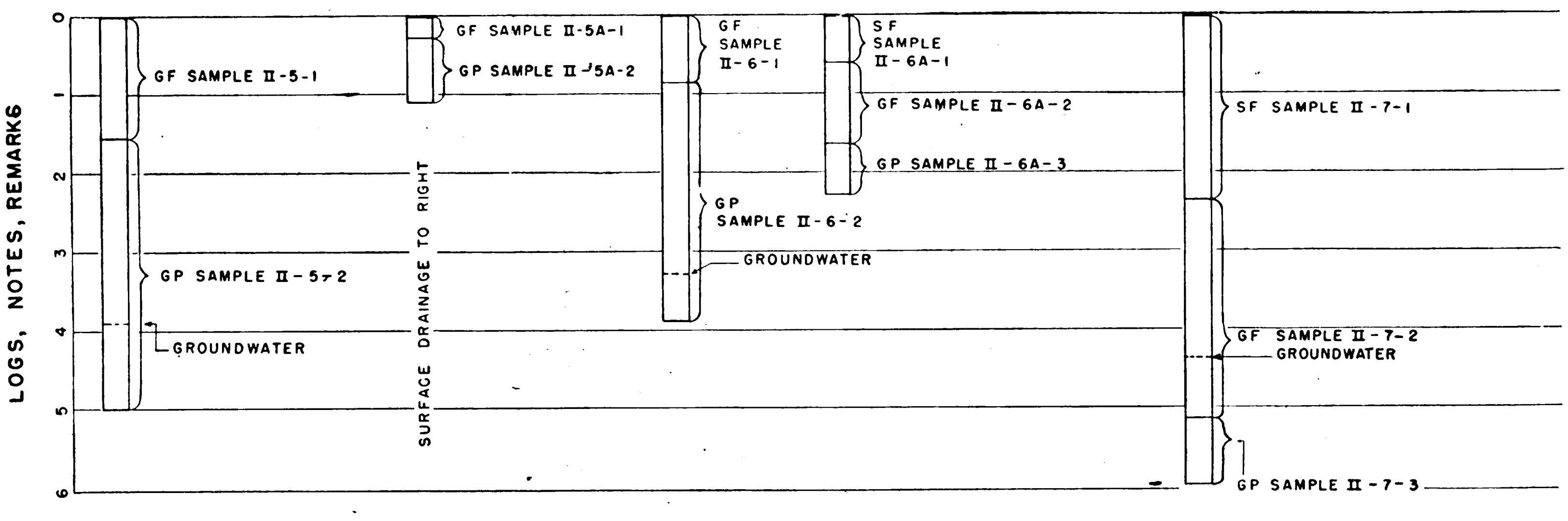


Figure 29. Section of typical soil profile sheet.



NOTE: INDIVIDUAL TESTHOLE SAMPLES OF SF, GF, AND GP SOILS ARE COMBINED TO FORM COMPOSITE SAMPLES OF THE THREE MATERIALS. EACH COMPOSITE SAMPLE IS REDUCED TO CONVENIENT SIZE BY QUARTERING AS PER APPENDIX III, PARAGRAPH 3

Figure 29. Section of typical soil profile sheet.—Continued.

five parallel lines: the preliminary center line, the two edges of the landing strip, and the lines midway between the center line and each edge. Levels are taken on each line at 100-foot intervals and at intermediate breaks or changes in the ground profile. Traverses are made of drainage lines and their catchment areas. From this information the position or direction of the center line is adjusted if necessary and grades are establshed for earthwork. (See ch. 13.)

(2) Locations of taxiways and hard standings may be established by similar survey methods. However, it is preferable to have a large-scale topographic map of the site for this purpose, especially if an extensive taxiway system must be provided. Recommended scale of the topographic map is 1:4,800 (1 inch=400 feet) with a contour interval of 2 feet over flat areas and a larger interval over rough terrain. Where time permits its preparation, a map at a scale of 1:1,200 (1 inch=100 feet) will allow scaling with acceptable accuracy of all horizontal distances including horizontal measurements for profiles. See TM 5–230 and 5–235 for complete information on surveying methods, plotting, and topographic drafting.

c. Soil survey. (1) A soil survey is made of the landing strip and taxiway areas for the following purposes: to obtain soil samples for inspection, classification, and testing; to develop soil profiles; to determine field drainage characteristics; and to determine location of the ground-water table and proximity of ledge rock. Auger holes (fig. 28) or test pits are dug at 1,000-foot intervals along two lines 75 feet each side of the landing-strip center line. Additional holes at intermediate points may be necessary to establish the profile if the soil varies. Fewer holes will suffice if the soil is uniform. In cut areas all holes should extend about 4 feet below final subgrade elevations and in fill areas 4 feet below ground elevation. A few holes should be carried deeper to determine the characteristics of lower strata.

(2) Soil samples from test holes are inspected and classified in the field by the methods explained in chapter 11. All samples should be identified by tags and placed in bags for further tests with the laboratory set (fig. 212).

(3) The position of the ground-water table is indicated by the level of free water standing in the test hole. However, many soil layers carry seepage slowly, and to determine ground-water level the holes should be left unfilled, but covered, and inspected after 24 hours. A mirror to direct sunlight into the hole, or a flashlight, is useful in detecting seepage. In dry seasons the action of water poured into test holes sometimes may indicate a water-bearing stratum where the water disappears rapidly from the hole.

(4) Results of the soil survey are recorded on soil-profile sheets as work progresses in the field. Figure 29 shows a typical form. This information is used in planning grading operations to make best use of soils encountered in cuts and in planning treatment of unsatisfactory soils (chs. 13 and 14). Figure 30 shows an actual soil profile exposed in a cut.

d. Meteorologic survey. If the airdrome is to be used for some time, daily recordings of meteorologic data should be started and systemmatically kept.

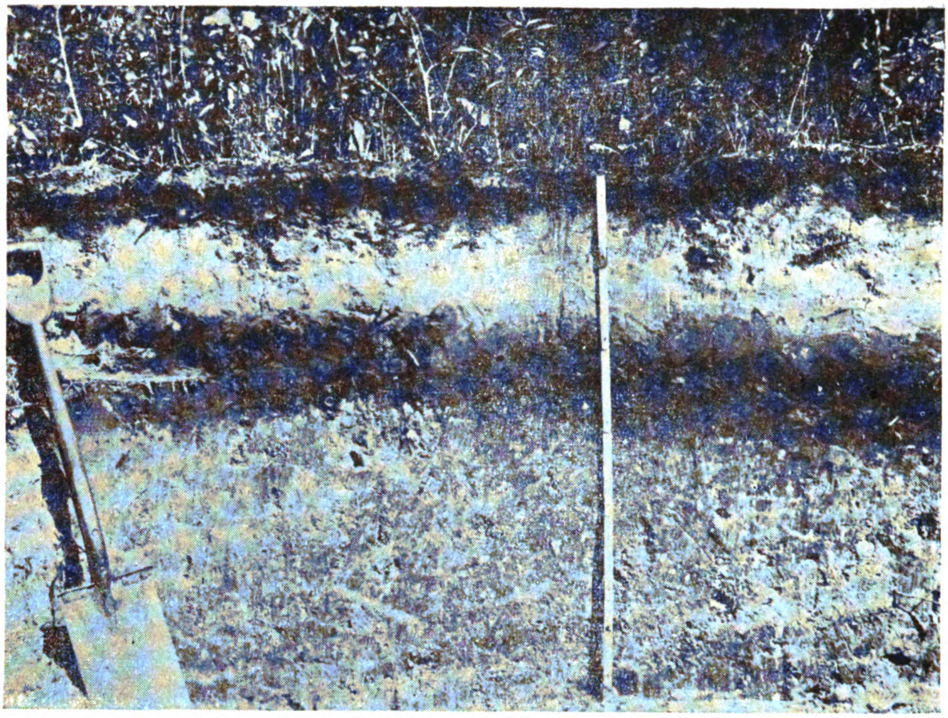


Figure 30. Face of a cut showing variations of soil in profile.

The log should include data on wind, rainfall, snow, fog, overcast, dust storms, and similar phenomena of importance.

80. MASTER PLAN. At sites scheduled for extensive development a master plan in skeleton form should be prepared to serve as a guide in coordinating piecemeal construction. A topographic map of scale 1:4,800 or larger, is convenient for this purpose. In the absence of such a map aerial photographs, photomaps, or field sketches may be used. The master plan should show the general arrangement and locations of the main elements of the *ultimate* airdrome including all landing strips, taxiways, roads, technical installations, camps, and dumps. It should show also the ultimate drainage scheme. Those parts of the airdrome scheduled for *immediate* construction should be identified prominently on the plan.

81. PLANNING FOR STAGE CONSTRUCTION (par. 52). Wherever possible, construction plans should provide for emergency use of an airdrome at successive stages of completion. This is a primary requirement where the operation depends upon air transport for supply. For example a cleared, smooth earth or turf strip can be used by cargo planes (fig. 31), and a smooth, compacted, and drained subgrade may serve fighter aircraft temporarily. Meanwhile another strip can be prepared or, if this is not practicable, spreading and compacting of base materials in layers on the subgrade can be coordinated with

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necessary use of the landing strip. Similarly, with proper coordination and work-planning steel landing mat may be laid while planes operate, but this procedure should be avoided if an alternate solution is possible.

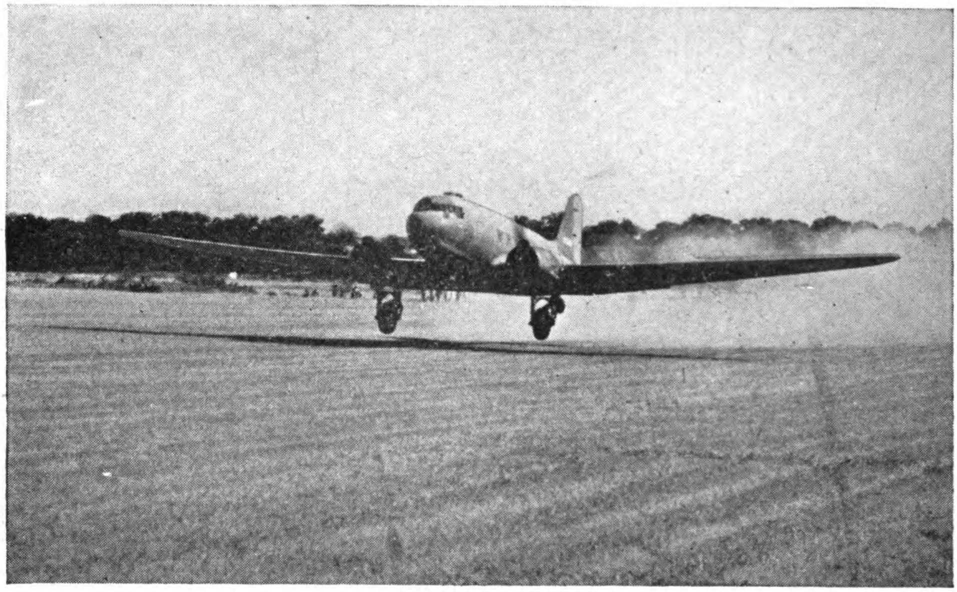

Figure 31. Cargo plane using temporary turf strip.

82. ENGINEERING DESIGN. **a.** The principal design problems are—
(1) Drainage system and drainage structures (par. 120).
(2) Design of runways, taxiways, and hard standings, including—

(*a*) Selection of soils encountered in cuts and their use to improve subgrade (par. 122b).

(*b*) Compaction or other stabilization of subgrade (par. 128).

(*c*) Type, thickness, and methods of constructing base course (ch. 15).

(*d*) Type, thickness, and methods of constructing pavement (chs. 19 and 20).

(3) Design of structures such as control tower, shelters, shops, warehouses, and other buildings (ch. 22).

b. Study of these problems requires survey information. Special investigations, such as soil studies with the laboratory set and trial processing of base material, frequently will be necessary. Such studies must be undertaken as quickly as possible so that designs and construction plans may be decided.

83. PRIORITIES. Establishment of priorities for work items is essential to assure concentration and coordination of effort. While there are no hard and fast rules for priorities, because no two situations are exactly alike, the following order applies to a typical first-stage construction situation.

Priority	Item
1	Security of construction troops and bivouac.
2	Access road.
3	One landing strip, cleared, drained, and graded, with temporary runway if required for initial use.
4	Approach zone, cleared of obstructing trees, poles, and towers.
5	Taxiway, alert apron, and temporary hard standings.
6	Fuel, supply, and ammunition dumps.
7	Service roads.
8	Technical facilities as required.

84. DETAILED CONSTRUCTION PLANS. Detailed plans include drawings annotated where necessary by notes or specifications, an estimate of quantities (tables IV and XXIV), and a progress or work schedule (table XXV). Drawings are in sufficient detail for laying out work on the ground and setting construction stakes for grading and drainage. From the estimate of quantities are determined materials and man-hour and machine-hour requirements. A progress schedule for the entire job then is made. This kind of planning assures full use of equipment and manpower and orderly construction in accordance with priorities. The work schedule also serves as a convenient means of checking daily progress for over-all supervision and control of the work. For explanation and illustration of a work schedule, see chapter 21.

CHAPTER 11

SOILS

85. IMPORTANCE. Knowledge of the physical properties of soils is essential in solving problems of design and construction of runways, taxiways, hard standings, roads, and foundations for structures. Because of the urgency of much of this construction usually neither time nor facilities are available for a complete laboratory study of the soils encountered. Accordingly the engineer must rely on his ability to identify soils and judge their properties from visual inspection and simple classification tests performed in the field. He must be able to decide promptly which of the available soils is best suited for the construction; whether drainage is necessary or feasible; whether a soil is sensitive to frost action; what type of treatment is practicable for stabilization of a given soil; and the relative economy of subgrade stabilization or extra thickness of base course.

86. WHAT CONSTITUTES SOIL. "Soil" is a general term which includes practically every type of earthen material, including artificial fill, soft shales, and partly cemented sandstones. Most soils consist mainly of a heterogeneous accumulation of mineral grains not cemented together. Voids between these grains may be filled partly or completely with water. In addition, some soils contain organic material in various forms and quantities. In peaty soils organic substances predominate, consisting largely of coarse, partly decomposed vegetable matter. In some clays organic material, present only in small quantities in colloidal form, has an important bearing on physical properties.

87. PRINCIPAL SOIL TYPES. For identification and classification purposes all soils can be grouped into five principal types: gravel, sand, silt, clay, and organic matter. Each has distinctive properties readily identified in the field. Likewise each type has distinct engineering characteristics of which practical use can be made. Paragraphs 88 to 92, inclusive, describe these types, give methods for their field identification, and explain their engineering characteristics.

88. GRAVEL. a. General description. Bulky mineral grains larger than about ¼ inch in diameter (coarser than a ¼-inch or No. 3 sieve) are called gravel. (See graphic scales on fig. 32.)

b. Identification. Gravel is identified readily by inspection.

c. Engineering characteristics. Next to solid bedrock, well-graded (par. 5d, app. III) and compacted gravel is the most stable natural foundation material. It also is desirable material for base and surface courses. Gravel is easy to compact, easy to drain, little affected by moisture, and not subject to frost action.

89. SAND. a. General. Sand consists of mineral grains ranging from about ¼ inch to 0.002 inch (0.05-mm) in diameter. (See graphic scales, fig. 32.) These dimensions include particles passing through a ¼-inch sieve and retained on a No. 270 sieve. Sand particles larger than a No. 20 sieve are called *coarse* and those smaller than a No. 80 sieve are called *fine.* (See table LXII for standard sieve dimensions.)

b. Identification. Sand is identified by visual inspection except when the particles are uniformly small. In that case care is required to distinguish between fine sand and silt. Dried sand exhibits no cohesion (does not hold together) and feels gritty.

c. Engineering characteristics. Well-graded, angular sand is a desirable foundation material. It is easy to drain, little affected by moisture, and ordinarily not affected by frost action. The finer and more uniformly graded a sand, the more it approaches silt, with correspondingly undesirable characteristics. However, confined sand provides an excellent subgrade. For this reason it works well when confined under steel landing mat. A sieve analysis readily distinguishes sand and silt. Although the No. 270 sieve represents the division between sand and silt sizes, for practical reasons the No. 200 sieve ordinarily is used in actual tests.

90. SILT. a. General description. Silt consists of natural mineral grains which pass a No. 270 sieve, lack plasticity (par. 91a.) and possess little or no cohesion when dry. The term "rock flour" commonly is used to describe inorganic silts of glacial origin.

b. Identification. Two simple tests performed in the field afford positive identification:

(1) SHAKING TEST. Prepare a pat of wet soil, adding water if necessary. Then shake horizontally in the palm of the hand. With typical inorganic silt this action causes water to come to the surface of the sample which now appears glossy and rather soft. Squeezing the sample between the fingers causes the water to disappear from the surface, and the sample quickly stiffens and finally cracks or crumbles.

(2) BREAKING TEST. Allow the sample to dry; test its cohesion and feel by crumbling with the fingers. Typical silt shows little or no cohesion when dry and possesses a smooth feel in contrast to the grittiness of fine sand, for which it is sometimes mistaken. Frequently silts are misclassified as clays because of their fineness and color.

c. Engineering characteristics. All types of silt are treacherous. Because of their inherent instability slight disturbances in the presence of water, such as traffic vibrations transmitted to a wet silt subgrade, may cause them to become soft or to change into a "quick" condition. When ground water or seepage is present silts are subject to intensive ice accumulation and consequent heaving when exposed to frost action. Silts are difficult to compact and to drain. Subdrainage is not effective in increasing their stability.

91. CLAY. a. General description. Clay consists of particles smaller than 0.0002 inch (0.005-mm). These particles are miscroscopic in size. Between certain moisture contents all clays display an adhesiveness characteristic of the physical property known as *plasticity,* which is used for classification purposes. Depending upon the proportion of coarser grains, clays vary from lean clays (low plasticity) to fat clays (high plasticity). Many clays, brittle in their undisturbed state, become soft and plastic upon being worked. As a result of alternate wetting and drying, vegetation and frost action, or general weathering clays may undergo radical changes in color and physical properties.

b. Identification. The character of clay in its plastic range and its hardness when dry afford means of identification.

(1) For examination in the plastic range a piece of clay is tested by working it with the fingers, adding water when the stiffness requires it. In this moistened condition its plasticity is evidenced by its susceptibility to kneading like dough. Plasticity also is indicated by the *ribbon* test. The ribbon is formed by placing a ball of kneaded soil between the thumb and index finger and drawing the index finger under the thumb as in closing the hand. Clay will form a long, thin, flexible ribbon that does not break under its own weight. This test readily differentiates clay from silt.

(2) Hardness of a *dried sample* of clay is measured by the intensity of finger pressure required to break up the sample. Much greater force is required to break dry clay than dry silt.

c. Engineering characteristics. The consistency of undisturbed clay is quite different from its characteristics while being worked in identification tests. As found in undisturbed beds it may range from hard through stiff, medium, soft, or extremely soft, depending upon the natural moisture content and degree of consolidation. Hard clay that cannot be remolded with ordinary finger pressure requires a pick for excavating. Soft clay can be excavated readily with a shovel and easily remolded by hand. Low resistance to deformation, high compressibility, imperviousness, and large expansion or contraction with changing moisture content are inherent properties of clays. Wet clays are impossible to compact. Clays absorb surface water or ground seepage slowly and retain it tenaciously, so subdrainage is ineffective.

92. ORGANIC MATTER. a. General description. Soils containing organic matter are *peaty soils,* consisting largely of partly decomposed vegetation, and *fine-grained plastic and nonplastic sediments,* containing varying amounts of finely divided vegetable matter such as organic sandy silt, organic silt, organic silt-clay, or organic clay.

b. Identification. (1) Organic matter in peaty soils is coarse and fibrous and identification is by visual inspection. In organic silts and clays, however, organic matter often is so finely divided it cannot be detected visually. In many cases the organic odor is strong enough to be detected easily. When in doubt the odor can be intensified by heating a sample quickly. Organic clays feel spongy in the plastic range as compared to inorganic clays.

(2) Field laboratory tests—liquid limit and plastic limit—can be used for identifying plastic organic soils. Tests on samples before and after oven-drying show a material decrease in these limits.

c. Engineering characteristics. All peaty and plastic organic soils are unsatisfactory subgrades because of their high compressibility and low resistance to deformation. In general they require either removal or a thick covering course of select soil.

93. SOILS AS FOUND IN PLACE. **a.** Soils in nature seldom exist separately as gravel, sand, silt, clay, or organic matter but are found as mixtures, with varying proportions of the five principal types. Each constituent contributes its characteristics to the mixture. Some combinations are excellent subgrade, base, and surfacing materials, such as a mixture of the right proportions of gravel, sand, silt, and clay. Such mixtures sometimes are found in nature. More frequently it is necessary to mix separate soils to produce a satisfactory combination.

b. Identification and classification of combined soils depend upon recognition of the individual and predominant constituents. Gravel and sand grains are identified by inspection. Proportions of gravel, sand, and combined silt-clay are determined by inspection or by a sieve analysis (par. 5, app. III). Examination of the combined silt-clay is made by methods described in paragraphs 90 and 91.

94. CLASSIFICATION OF SOILS. **a. Corps of Engineers (Casagrande) system.** The engineering classification of natural soils, summarized in table V, is used for airdromes and roads. For convenience the table also includes the corresponding soil classes in the Public Roads Administration scheme that is used widely in civil practice, and explains general classifications of soils and aggregates in terms of *plasticity* and *gradation.* Representative samples of soil are obtained in the soil survey (par. 79c). These are examined and classified on the spot. When classified, the engineering characteristics of the soil are disclosed. Proper use of the soil and appropriate construction measures are shown in table V. If time permits, more elaborate soil studies can be made with the field laboratory set, as needed in difficult situations involving important roads or airdromes. (See app. III for test procedures; and par. 16, app. III, for an explanation of the use of test results for distinguishing the various fine-grained soils, a problem sometimes difficult to solve by simple hand methods.)

Table V. Soil classification—Corps of Engineers (Casagrande).

1		2	3	4		5	6
Major divisions		Soil groups and typical names	Group symbols[1]	General identification		Observations and tests relating to material in place	Principal classification tests (on disturbed samples)
				Dry strength	Other pertinent examinations		
Coarse-grained soils	Gravel and gravelly soils.	Well-graded gravel and gravel-sand mixtures; little or no fines.	GW	None.	Gradation, grain shape.	Dry unit weight or void ratio; degree of compaction; cementation; durability of grains; stratification and drainage characteristics; ground-water conditions; traffic tests; large-scale load tests; or California bearing tests.	Sieve analysis.
		Well-graded gravel-sand-clay mixtures; excellent binder.	GC	Medium to high	Gradation, grain shape, binder examination, wet and dry.		Sieve analysis; liquid and plastic limits on binder.
		Poorly graded gravel and gravel-sand mixtures; little or no fines.	GP	None.	Gradation, grain shape.		Sieve analysis.
		Gravel with fines, very silty gravel, clayey gravel, poorly graded gravel-sand-clay mixtures.	GF	Very slight to high.	Gradation, grain shape, binder examination wet and dry.		Sieve analysis; liquid and plastic limits on binder if applicable.
	Sands and sandy soils.	Well-graded sands and gravelly sands; little or no fines.	SW	None.	Gradation, grain shape.		Sieve analysis.
		Well-graded sand-clay mixtures; excellent binder.	SC	Medium to high.	Gradation, grain shape, binder examination wet and dry.		Sieve analysis, liquid and plastic limits on binder.
		Poorly graded sands; little or no fines.	SP	None.	Gradation, grain shape.		Sieve analysis.
		Sand with fines; very silty sands, clayey sands, poorly graded sand-clay mixtures.	SF	Very slight to high.	Gradation, grain shape, binder examination wet and dry.		Sieve analysis, liquid and plastic limits on binder if applicable.
Fine-grained soils (containing little or no coarse-grained material).	Fine-grained soils having low to medium compressibility.	Silts (inorganic) and very fine sands, Mo, rock flour, silty or clayey fine sands with slight plasticity.	ML	Very slight to medium.	Examination wet (shaking test and plasticity).	Dry unit weight, water content, and void ratio. Consistency, undisturbed and remolded. Stratification. Root holes. Fissures, etc. Drainage and ground-water condition. Traffic tests, large-scale load tests, California bearing tests, or compression tests.	Sieve analysis, liquid and plastic limits if applicable.
		Clays (inorganic) of low to medium plasticity, sandy clays, silty clays, lean clays.	CL	Medium to high.	Examination in plastic range.		Liquid and plastic limits.
		Organic silts and organic silt-clays of low plasticity.	OL	Slight to medium.	Examination in plastic range. odor.		Liquid and plastic limits from natural condition and after oven-drying.
	Fine-grained soils having high compressibility	Micaceous or diatomaceous fine sandy and silty soils; elastic silts.	MH	Very slight to medium.	Examination wet (shaking test and plasticity).		Sieve analysis, liquid and plastic limits if applicable.
		Clays (inorganic) of high plasticity; fat clays	CH	High.	Examination in plastic range.		Liquid and plastic limits.
		Organic clays of medium to high plasticity.	OH	High.	Examination in plastic range, odor.		Liquid and plastic limits from natural condition and after oven-drying.
Fibrous organic soils with very high compressibility.		Peat and other highly organic swamp soils.	Pt	Readily identified.		Consistency, texture, and natural water content.	

Table V. Soil classification—Corps of Engineers (Casagrande).—Continued.

1		7	8	9	10	11	12	13	14	15
Major divisions		Value as foundation when not subject to frost action[2]	Value as base directly under wearing surface[3]	Potential frost action	Shrinkage expansion elasticity	Drainage characteristics	Compaction characteristics and equipment	Solids at optimum compaction, u, lb. per cu. ft. and void ratio, e^3	Calif. bearing ratio for compacted and soaked specimen	Comparable group in public roads classification.
Coarse-grained soils.	Gravel and gravelly soils.	Excellent.	Good to excellent.	None to very slight.	Almost none.	Excellent.	Excellent, tractor.	$u>125$ $e<0.35$	>50	A-3
		Excellent.	Fair to excellent.	Medium.	Very slight.	Practically impervious.	Excellent, sheepsfoot roller.	$u>130$ $e<0.30$	>40	A-1
		Good to excellent.	Poor to good.	None to very slight.	Almost none.	Excellent	Good, tractor.	$u>115$ $e<0.45$	25-60	A-3
		Good to excellent.	Poor to good.	Slight to medium.	Almost none to slight.	Fair to practically impervious.	Good, close control essential, rubber-tired roller, tractor.	$u>120$ $e<0.40$	>20	A-2
	Sands and sandy soils.	Good to excellent.	Poor to good.	None to very slight.	Almost none.	Excellent.	Excellent, tractor.	$u>120$ $e<0.40$	20-60	A-3
		Good to excellent.	Poor to good.	Medium.	Very slight.	Practically impervious.	Excellent, sheepsfoot roller.	$u>125$ $e<0.35$	20-60	A-1
		Fair to good.	Not suitable.	None to very slight.	Almost none.	Excellent.	Good, tractor.	$u>100$ $e<0.70$	10-30	A-3
		Fair to good.	Not suitable.	Slight to high.	Almost none to medium.	Fair to practically impervious.	Good, close control essential, rubber-tired roller.	$u>105$ $e<0.60$	8-30	A-2
Fine-grained soils (containing little or no coarse-grained material)	Fine-grained soils having low to medium compressibility	Fair to good.	Not suitable.	Medium to very high.	Slight to medium.	Fair to poor.	Good to poor, close control essential, rubber-tired roller.	$u>100$ $e<0.70$	6-25	A-4 A-6 A-7
		Fair to poor.	Not suitable.	Medium to high.	Medium.	Practically impervious.	Fair to good, sheepsfoot roller.	$u>100$ $e<0.70$	4-15	A-4 A-6 A-7
		Poor.	Not suitable.	Medium to high.	Medium to high.	Poor.	Fa.r to poor, sheepsfoot roller.	$u>90$ $e<0.90$	3-8	A-4 A-7
	Fine-grained soils having high compressibility.	Poor.	Not suitable.	Medium to very high.	High.	Fair to poor.	Poor to very poor.	$u<100$ $e>0.70$	< 7	A-5
		Poor to very poor.	Not suitable.	Medium.	High.	Practically impervious	Fair to poor, sheepsfoot roller.	$u>90$ $e<0.90$	< 6	A-6 A-7
		Very poor.	Not suitable.	Medium.	High.	Practically impervious.	Poor to very poor.	$u<100$ $e>0.70$	< 4	A-7 A-8
Fibrous organic soils with very high compressibility.		Extremely poor.	Not suitable.	Slight.	Very high.	Fair to poor.	Compaction not practical. Remove and replace with select material.			A-3

NOTES

[1] Legend for Group Symbols (column 3)

G—Gravel.
S—Sand.
M—Mo, very fine sand, silt, rock flour.
F—Fines, material $<$ 0.1-mm.
L—Low to medium compressibility.
H—High compressibility.
C—Clay.
Pt—Peat.
O—Organic.
W—Well-graded.
P—Poorly-graded.

[2] In column 7, values are for subgrade and base courses, except for base courses directly under wearing surface. Values in columns 7 and 8 are for guidance only. Design should be based on test results.

[3] Unit weights in column 13 apply only to soils with specific gravities ranging between 2.65 and 2.75.

Plasticity classification. For many purposes, as when dealing with compaction, it is convenient to group soils in two broad classifications on the basis of cohesion in the dried state (dry strength):

(1) *Noncohesive (cohesionless) soils* are all noncemented sands, gravels, and sand-gravel mixtures, containing little or no plastic clay. They develop practically no cohesion when dry. They are also called *granular* or *nonplastic soils.*

(2) *Cohesive soils* are all fine-grained *plastic soils* and include sandy or gravelly soils containing enough plastic clay as binder to create upon drying a coherent mass which cannot readily be broken up into individual grains.

Gradation classification. The following terms are used to classify soil and aggregates on the basis of size and gradation:

(1) *Graded aggregate* is one in which there is a continuous representation of particle sizes from coarse to fine, the coarser sizes being many times larger than the finer sizes (fig. 32).

(2) *Dense-graded aggregate* is one that consists of particles graded in size from coarse to fine in such proportions that when compacted the voids are reduced to exceedingly small size. The proportion of fine particles passing No. 200 sieve usually is more than 5 per cent. The term "well-graded" is also used to describe such an aggregate. A typical aggregate of this class has a smooth curve of gradation that falls within the limits shown in figure 32.

(3) *Open-graded aggregate* is similar to a dense-graded aggregate except that it has a smaller proportion of fine particles, usually less than 5 percent passing a No. 200 sieve.

(4) *Macadam aggregate* is an open-graded aggregate consisting primarily of coarse particles with a restricted size range such as 2½ to 1 inch, or 1¼ to ½ inch.

(5) *Coarse aggregate* consists of particles larger than about ¼ inch (retained on a No. 3 sieve).

(6) *Fine aggregate* consists of particles smaller than about ¼ inch (passing through a No. 3 sieve).

b. Relation between Corps of Engineers system and other systems of classifying soils. (1) Table VI shows the approximate geologic and agricultural equivalents of the Corps of Engineers soil classes described in table V. This conversion may be used to interpret soil data obtained from geological and agricultural maps or surveys such as are published by many governments. (See par. 61.)

(2) The geological classification applies strictly to size of grain in well-sorted or sieved materials. Since natural soils and sediments commonly contain a range of different sizes of grains, the field classification is in terms such as *sandy silt, gravelly sand,* and *silty clay.*

(3) In both geological terminology and agricultural soil classification the term "soil" implies a mixture of distinegrated rock material and organic matter (humus) in which plants grow. In the Corps of Engineers usage soils include not only the organic zones but all unconsolidated rock materials. Therefore table VI shows a comparison between terms applying to similar sizes of grains. It should be clearly understood that only a sieve analysis (par. 5, app. III) gives exact information on the grain-size distribution (gradation) of a natural soil or sediment.

TABLE VI. Geological and agricultural equivalents of Corps of Engineers soil classifications.

Corps of Engineers classification		Geologic texture classes — Name	Agricultural soil terms
Gravel and gravelly soils.	GW GC GP	Boulder Cobble Pebble	Gravel
	GF	Granule (or grit)	*Gravelly loam:* predominance of gravel.
Sands and sandy soils.	SW SC and SP	Very coarse sand Coarse sand	*Sandy loam:* predominance of sand.
	SF	Medium sand	
		Fine sand	*Loam:* equal proportions sand, silt, and clay.
		Very fine sand	
Fine-grained soils with low compressibility.	ML CL MH	Silt	*Silt loam:* predominance of silt.
Fine-grained soils with high compressibility.	OL CH	Clay	*Clay loam:* predominance of clay.
	OH		*Clay:* nearly all clay.

c. Other classifications. In addition to the foregoing classifications there are commonly applied to soils many descriptive terms which relate to geologic origin, outstanding physical properties, or regional distribution. Following is a list of some important ones:

(1) ADOBE. Calcareous sandy silts and sandy-silty clays as found in the semiarid regions of the southwestern United States.

(2) CALCAREOUS. Soils containing an appreciable content of calcium carbonate, usually from limestone.

(3) CALICHE. Soft limestone containing varying percentages of silt and clay as found in the southwestern United States.
(4) CORAL. Calcareous, rocklike material formed by secretions of marine organisms. Found in most tropical areas.
(5) CINDERS (scoria). Soil composed of particles of volcanic origin.
(6) DISINTEGRATED GRANITE. Granular soil derived from advanced weathering and disintegration of granite rock.
(7) GUMBO. Sticky, highly plastic clay.
(8) LOAM. Loosely used term applied most frequently to sandy-silty topsoils containing a trace of clay.
(9) LOESS. Silty soil of aeolian (wind-blown) origin. Characterized by a loose, porous structure which permits it to stand in cuts with vertical walls.
(10) MARL. Richly calcareous clays, silts, and fine sands common in the Gulf Coast area of the United States.
(11) MICACEOUS. Soils containing sufficient mica flakes to give the soil a distinctive appearance.
(12) TILL. Unsorted deposit of glacial material containing mixtures of widely different sizes ranging from boulders to clay.

95. FROST-ACTION SOILS. a. Seasonal frosts. Soils subject to frost action are well-graded soils containing more than 3 percent by dry weight of particles less than 0.02-mm (0.0008 inches) in size, and uniformly graded soils containing more than 10 percent of particles less than 0.02-mm in size. In all questionable cases the percentage by weight of sizes below the critical diameter of 0.02-mm should be determined (par. 5, app. III). For a discussion of the effect of frost action on stability see paragraph 96. For information on design of bases where frost action is a factor see paragraphs 131h and 162.

b. Permanently frozen ground. (1) In northern areas of Alaska, Canada, Greenland, and Siberia complex construction problems are caused by permanently frozen ground (permafrost). The destructive effects of frost on roads, runways, and buildings are dangerous and can seriously interrupt airdrome operations if proper provisions are not made in design, construction, and maintenance. The stresses caused by frost are so great that they cannot be treated by extreme rigidity or strength in construction.
(2) In permafrost areas two zones of frost activity are present: the *active layer* near the surface, which freezes in winter and thaws in summer; and the *permanently frozen ground,* which never thaws. The thickness of the active layer ranges from less than 1 foot near the northern edge of permafrost regions to 14 feet in areas south of the 55th parallel of latitude. It is thicker in sandy ground and thinner in clays and peats. The bottom of the permafrost layer is at a depth where the internal temperature of earth prevents freezing.
(3) Some of the important effects of disturbing thermal equilibrium by construction upon permafrost areas are as follows:

(*a*) Swelling of the ground (frost heaving), producing frost blisters, mounds, icing mounds, and peat mounds.

(*b*) Settling and caving during thawing, producing mudflows, landslides, soil creep, and frost boils.

(*c*) Icings or formations of surface ice, producing rough icefields, icing mounds, and river icings.

(*d*) Formation of cavities, called *thermokarst,* including surface cracks, cave-ins, funnels, sinks, valleys and sag basins, and cave-in lakes.

(4) In locating structures, roads, and runways in permafrost areas three principal factors must be considered:

(*a*) Texture of the ground.

(*b*) Temperature of the ground and air.

(*c*) Hydrology of the area.

The primary consideration is to avoid silty sands and silty clays. In airdrome construction it may be necessary to strip a suitable depth of silty material and replace it with a sand of proper texture.

(5) Runways may be built in tundra country with preliminary drainage of excess surface water and subsequent covering with granular base-course material and flexible-type pavements. The surface is likely to suffer from year to year some warping detrimental to rigid-type pavements. Satisfactory runways can be built if the undisturbed surface of the ground is covered with a layer of granular material having low heat conductivity, for example: volcanic cinders, slag, or porous lava. The thickness of the insulating layer should conform to criteria shown in paragraph 131 for frost action soils.

96. STABILITY. A stable subgrade or base course is one that will not displace under wheel loads. Stability depends upon a combination of some or all of the following factors: size gradation, angularity of particles, character and proportion of binder in the mixture, degree of compaction, and moisture content. Because moisture content exerts a vital influence upon stability, drainage is important to control moisture and to minimize the effects of frost action in cold climates.

a. Particle-size gradation. Figure 32 shows gradation limits typical of soil or aggregate mixtures that have stable characteristics. This chart may be used as a guide in judging available materials and in proportioning mixtures for base courses. The proportion of fine material passing through a No. 200 sieve is particularly important and should be controlled. The limiting curves are drawn for a 1-inch maximum particle size, but they may be applied to others by translating them horizontally on the chart until point "A" is at the scale value of the maximum particle size of the aggregate under consideration.

b. Shape of particles. Angularity of particles contributes to stability through mechanical interlocking developed by compaction from traffic or rolling. In some types of construction, such as dry or water-bound macadam (par. 132j), mechanical interlock is the principal stability factor.

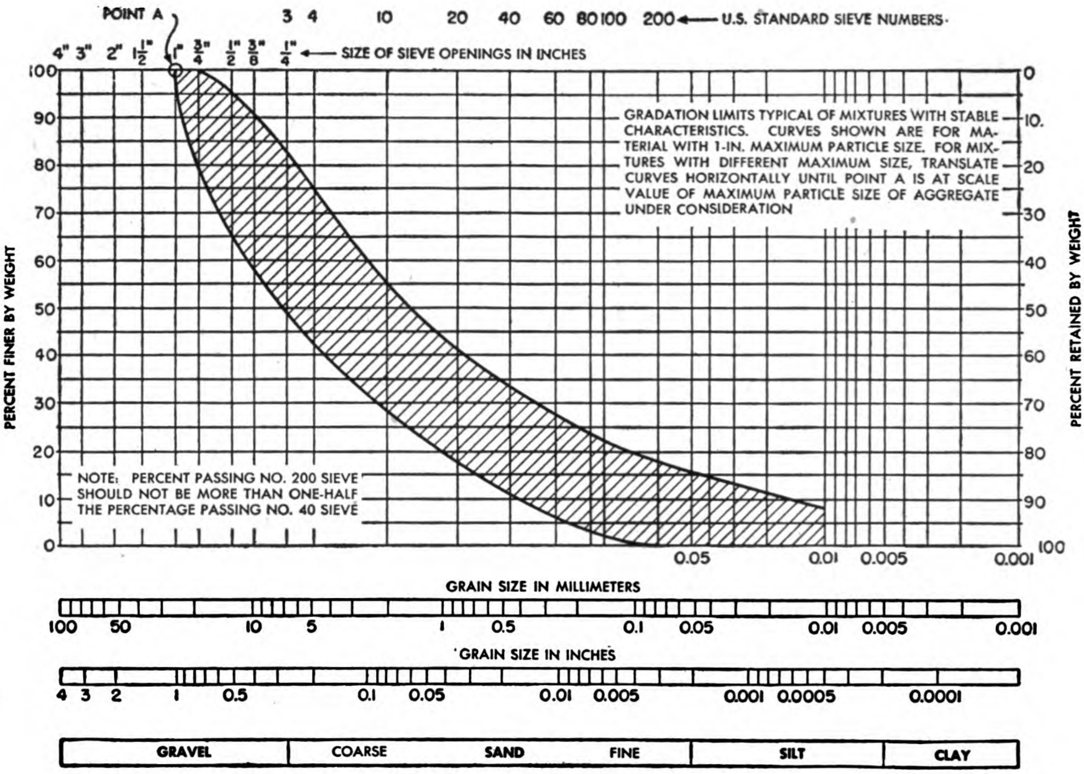

Figure 32. Gradation limits for stable mixtures.

c. Binder. (1) CLAY. In mixtures of gravel, sand, silt, and clay the fraction passing the No. 10 sieve is called soil mortar, and the fraction passing the No. 40 sieve is called soil binder. The clay in the binder is the active binding agent. The proportion and character of the binder, together with moisture content, exert an important influence on the stability of the mixture. The quality of the binder is indicated by the plasticity index and shrinkage of the fraction of the total mixture passing the No. 40 sieve (par. 9, app. III). Recommended values of plasticity index and shrinkage for base materials are given in chapter 12. *Too much clay in a base course is harmful and must be avoided wherever moisture is a factor.* Even with good quality binder and proper particle-size gradation, mixtures of this type are affected by water. They tend to soften and rut when wet and they ravel and are dusty in dry weather. Hence, with changing moisture conditions considerable maintenance is necessary under heavy traffic. To obviate these difficulties dust palliatives or surface treatments often are applied or a special binder such as bitumen (par. 105) is used instead of clay.

(2) BITUMINOUS BINDER. Bituminous binder, mixed into a runway surface, has some important advantages over clay, chiefly resistance to water and freedom from dust. Its chief disadvantage is that construction is difficult or impossible in wet or cold weather. The quantity of bituminous binder must be closely controlled; too much bitumen gives a soft, unstable mixture, and too

little gives a loose, porous, unbound mixture. When bituminous binder is used the mixture should contain little or no clay but the aggregate should be well-graded from coarse to fine, with sufficient dust (filler) passing a No. 200 sieve to produce a dense, stable course when consolidated.

d. Compaction. Compaction aids stability by forcing particles of a mixture into a dense, closely packed, interlocked condition. Two elements—equipment and moisture—are important. When a soil is well-compacted during construction subsequent absorption of excess moisture, and consequent softening, is reduced greatly. Therefore, compaction is important for continued stability in service. Table V shows types of equipment best suited for compaction of various soils. For proper compaction of *plastic soils* the quantity of water is highly important. For each plastic soil there is a moisture content, called optimum moisture, at which it will compact to greatest density under particular equipment. Optimum moisture content varies from about 17 to 20 percent of dry weight for fine-grained soil and from 7 to 10 percent for a well-graded aggregate containing soil binder. Soil at optimum moisture content feels slightly damp and firm when squeezed in the hand. Determinations may be made with the field laboratory set as a guide for control by visual inspection and hand squeezing. (See par. 10, app. III.)

e. Moisture and drainage. All subgrades, even in dry climates, tend to accumulate moisture after they are covered with a pavement. Poorly compacted subgrades of fine-grained soil soften appreciably with excess moisture and this softening is accelerated by the impact and vibrations of traffic. The principal function of drainage is to prevent excess moisture accumulation and thus to preserve stability. Two sources of water are involved: surface water from rain or snow, and ground water.

f. Frost action. Detrimental frost action on runways and roads is closely related to drainage. If drainage is not entirely successful in preventing ground water from reaching the subgrade the result of freezing is the accumulation of layers or lenses of ice in the subgrade soil. In some cases the evidence of frost action is a lifting or heaving of the surface. The amount of ice accumulation or heaving depends upon the character of the subgrade soils. Extremely fine sands and silts (table V) are most susceptible. Compacted plastic soils heave only moderately because of their extremely low permeability and the consequent small amount of water available to freeze. *Greatest reduction in stability occurs when the ice melts, causing saturation of the subgrade.* In this condition the subgrade rapidly approaches a liquid condition under traffic and in extreme cases breaks and erupts in failures called "frost boils." Therefore, drainage is highly important both to minimize the amount of water that may reach the freezing zone and, during thaws, to permit ready escape of melted ice water from the base course and the top of the subgrade. Subgrades of soils particularly susceptible to frost action should be covered with a blanket or insulation course (par. 127).

97. PRACTICAL USE OF SOIL INFORMATION. a. The soil classification scheme shown in table V is arranged for practical use in evaluating subgrades and designing base courses without using laboratory equipment. When a soil material has been identified and classified by the simple visual and hand methods, explained in paragraphs 88 through 93, its general value as subgrade or base material is obtained directly from columns 7 and 8 of table V. Column 14 shows its approximate California bearing ratio (CBR), which is used in connection with figure 68 to estimate the required thickness of the base course. Drainage characteristics are shown in column 11. These should be considered carefully in deciding the drainage plan. For example, since a soil that is practically impervious does not respond to subdrainage an elaborate subdrainage system is unwarranted. Instead, drainage should be designed to keep surface water from filtering down into the subgrade and to intercept ground-water seepage toward the runway from adjacent side areas. In column 12 are shown compaction characteristics and types of equipment that should be used to obtain compaction during construction.

b. There is no standard design and construction procedure for building stable runways, taxiways, and roads. Each site presents peculiar problems. The solution in each case should start with an evaluation of the soil and the base materials available. The effects of weather and ground-water conditions at the site and the topographic limitations on disposal of drainage water must be considered. The design weighs these factors and devises a solution aimed at achieving maximum stability (par. 96) with the equipment at hand and within the time available. Construction procedures then are arranged to accomplish the result.

98. EXPEDIENT SOIL TESTS. a. Gradation. A sieve analysis of an aggregate furnishes data on its particle-size distribution from which a gradation curve (fig. 280) may be drawn. (For detailed instructions on test procedure see par. 5, app. III.) An expedient that may be used in lieu of a sieve analysis is performed with a glass fruit jar of about 1-quart capacity. The jar is one-quarter filled with a *representative sample* of aggregate and water is added until the jar is three-fourths filled. With the top covered the jar is shaken vigorously for about a minute, then set at rest upright. Approximate gradation is indicated by the separation of the particles in the jar, coarse to fine from bottom to top. Particles remaining in suspension after ½ minute are silt and clay. Particles remaining in suspension after 1 hour are clay.

b. Shrinkage and expansion. The amount of dimension change a soil undergoes with changing moisture content indicates the effect of water on its stability. *Base material should have no appreciable shrinkage or expansion.* Fine-grained subgrade soils that have a swell of more than 2 or 3 percent or a linear shrinkage of more than 3 to 5 percent are poor and ordinarily have low stability when wet. Expansion, or swell, is measured in making the bearing-ratio test (par. 11, app. III). However, this test requires laboratory equipment. Instead, a simple field expedient may be used to determine linear shrinkage. Onto a loose representative sample of the soil fraction passing through a No. 10 sieve water is dripped until its moisture capacity is satisfied without free water remaining on the surface. The moist soil then is worked into a mold 1 by 1 inch, or 1½ by 1½ inches, in cross section, and 10 inches long. Its wet length is carefully measured and, after the sample has dried out, its dry length. The percent change in length is percent of shrinkage. Where a mold is not handy, the moist sample may be rolled into the approximate shape and size of a cigar and two pins placed in it about 5 inches apart. The decrease in distance between the pins from wet to dry condition is measured and expressed as a percentage, as above.

99. SOURCES OF INFORMATION ON FOREIGN SOILS. Soils in foreign countries may have to be utilized without adequate time and facilities for study. Information may be obtained from allied troops or from local sources; otherwise the engineer must rely upon his observation, analysis, and judgment. In judging foreign soils it is important to remember that soils developed under the same conditions of climate, topography, and parent material are related and have similar engineering characteristics. This makes it possible to translate and apply soils experience from one region to another. Foreign soils should be judged on the basis of their engineering characteristics, as disclosed by identification and test procedures explained in this chapter, which are universally applicable. Observation of soils used in local road construction often will disclose valuable clues for airdrome construction. Many foreign countries have published agricultural soil-classification maps and geological maps which may be helpful.

100. USE OF AERIAL PHOTOGRAPHS FOR SOIL INFORMATION. From a study of aerial photographs of an area whose geology, soil, and vegetation characteristics are known, often it is possible to learn something of the soils of adjacent areas in the same region, by a study of aerial photographs of the unknown area.

a. Vegetation. Vegetation in any region is influenced by soil conditions topography, and climate. Knowledge of the relationships among plant life, soils, and topography in one area may provide clues to soil conditions in an adjacent area through identification of vegetation in aerial photographs where elevation, rainfall, and topography are comparable. In many regions of subhumid and semiarid climate the areas of outcrop of sandy rock formations, such as sandstones or sandy shales, have sandy soils and support abundant forest growth. Adjacent belts of clay soils are grassy prairies. Thus areas of sandy soils in some regions are indicated by the presence of forests of pine or other conifers. Similarly in some regions the presence of granular material immediately below the top soil is indicated by the type of grasses. The clay

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and peat soils of swamps frequently support dense growths of reeds, cattails, or bamboo thickets.

b. Soil color. Differences in soil colors can be seen on aerial photographs of many areas especially if the exposures were made on panchromatic film. This factor allows a small amount of ground observation to be applied to a much larger area shown in the photograph. Soil colors often show distinctly through standing grain crops, thin grass, or scattered woodlands. Plowing and harrowing affect soil color and must be recognized in studies of cultivated areas.

c. Topography and drainage. Distinctive types of topography as shown on aerial photographs convey much information on soils if properly interpreted. All areas differ in detail from place to place but some generalizations concerning relationships between topography and soils can be made.

(1) MOUNTAINOUS REGIONS. Mountain ridges and peaks generally have thin soils and large areas of bare rock. The lower slopes contain large fan-shaped or elongated areas of coarse gravel and rock fragments. Finer sands, silts, and clays occur in greater abundance near the middle of intermountain valleys. Such valleys contain a wide range of soil types and in many regions they provide good airdrome sites.

(2) PLATEAUS. Most plateaus have relatively thin soils underlain by bedrock. Large level areas provide favorable sites for airdromes, and rock materials for crushing usually can be developed in quarries with little overburden. In the valleys, however, sand and gravel may occur in terraces or along the stream bed.

(3) PLAINS. On aerial photographs of large plains the best indications of soil conditions are the drainage patterns or other local variations. Large valleys may have sand and gravel deposits in the stream bed or in terraces above the present stream level. Valleys with meandering streams generally have predominantly fine materials, chiefly clay, silt, and fine sand.

(4) GLACIATED AREAS. These are characterized by numerous lakes and swamps and a scarcity of well-developed valleys. The low ridges or moraines at the margins of glaciated areas, the shores of glacial lakes, and the valleys of streams in and near the area all are potential sources of sand and gravel. The soils of glaciated areas range from clays to sand and gravel. In general, the rougher surfaces of glacial drift indicate higher proportions of gravel.

(5) AEOLIAN SOILS. Hills of half-moon or dune shapes suggest soil of wind-blown origin that implies a definite limit of maximum particle size as well as characteristic gradation. The soil may be coarse and sandy or fine loess. Vegetation and local erosion may differentiate them. Erosion slopes in sandy soil are similar to the angles of repose of sand piles, whereas eroded loess stands in steep banks.

CHAPTER 12

MATERIALS

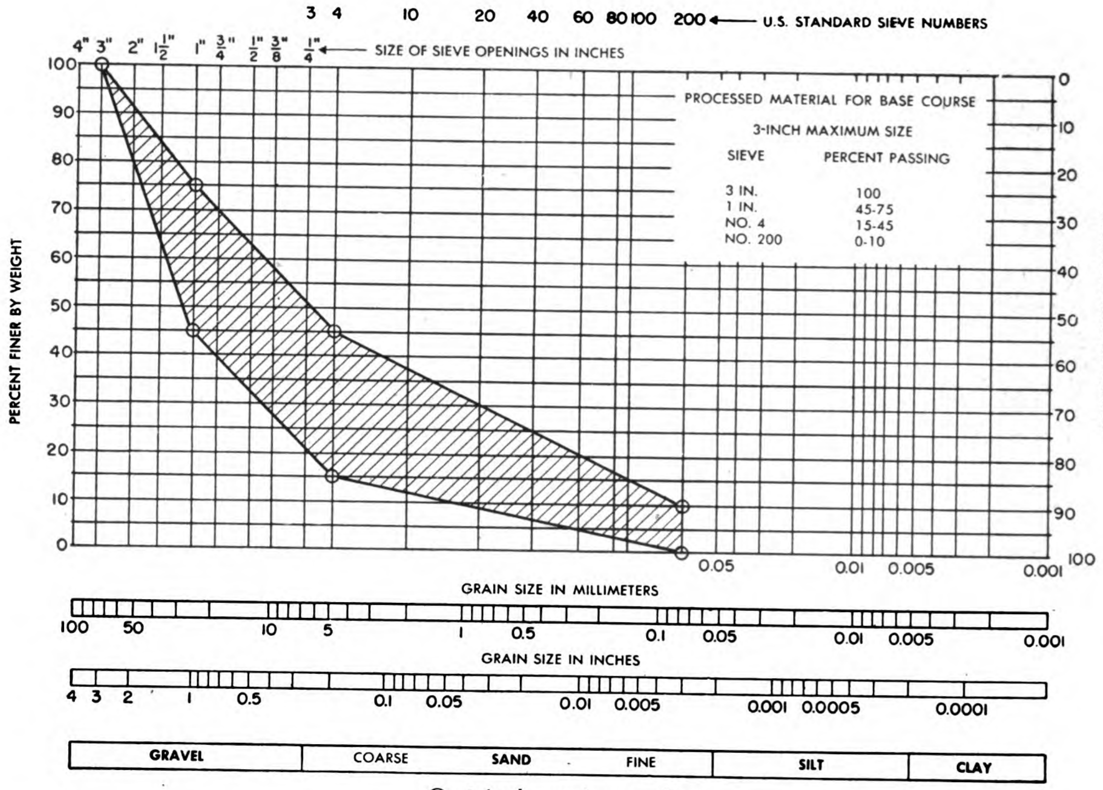
101. BASE-COURSE MATERIALS. a. Natural materials. (1) DESCRIPTION. Natural materials include pit-run gravel, sand-clay, disintegrated granite, talus rock, mine tailings, caliche, scoria, coral, limerock, shell, volcanic cinders and clinkers, iron ore, or other select materials that do not soften appreciably when wet or pulverize under traffic.

(2) GRADATION. The gradation curves of the materials listed above generally should fall within the limiting curves shown in figure 32. However, other properties make some of these materials sufficiently stable without meeting these gradation requirements. For example, thoroughly compacted coral, limerock, and caliche frequently develop a cementing action that provides good stability. Angular talus rock develops stability from mechanical interlock produced by compaction. Maximum particle size should not exceed three-fourths and preferably two-thirds the thickness of the base-course layer in which it is incorporated.

(3) PLASTICITY INDEX. The plasticity index (par. 9, app. III) of the fraction passing No. 40 sieve should be between 3 and 9, but if a bituminous surface treatment or a pavement is to be added, it should not exceed 6. If facilities are not available to determine the plasticity index, the linear shrinkage test described in paragraph 98 may be used. The fraction passing a No. 10 sieve should show no appreciable shrinkage.

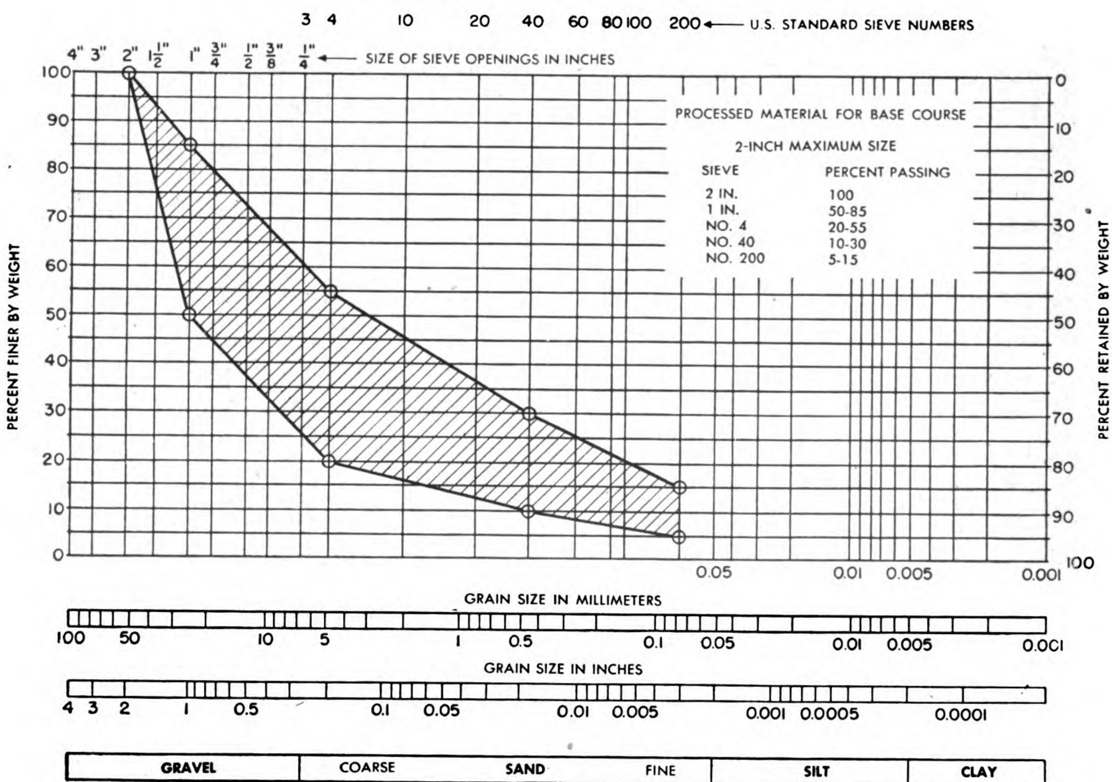
(4) STABILITY. The stability developed by the compacted material should meet the requirements shown in table XII. If a laboratory set is not available, stability may be tested by laying a trial section and observing its performance under the wheels of a heavily loaded vehicle. Such tests should be made with moisture conditions approximating the average severe conditions expected at the site.

b. Processed materials. (1) DESCRIPTION. Processed materials are prepared by crushing, screening, or blending to produce a composite base material which, when compacted, is stable and has other desired properties. Gravel, ledge rock, talus rock, coarse mine tailings, and similar hard, durable materials are the usual sources. Because the crushed or screened aggregate from these sources often is deficient in fines it may be necessary to blend some selected fines to get the desired gradation. Rock dust, fine sand, or soil containing some clay may be added and mixed either in the processing plant or on

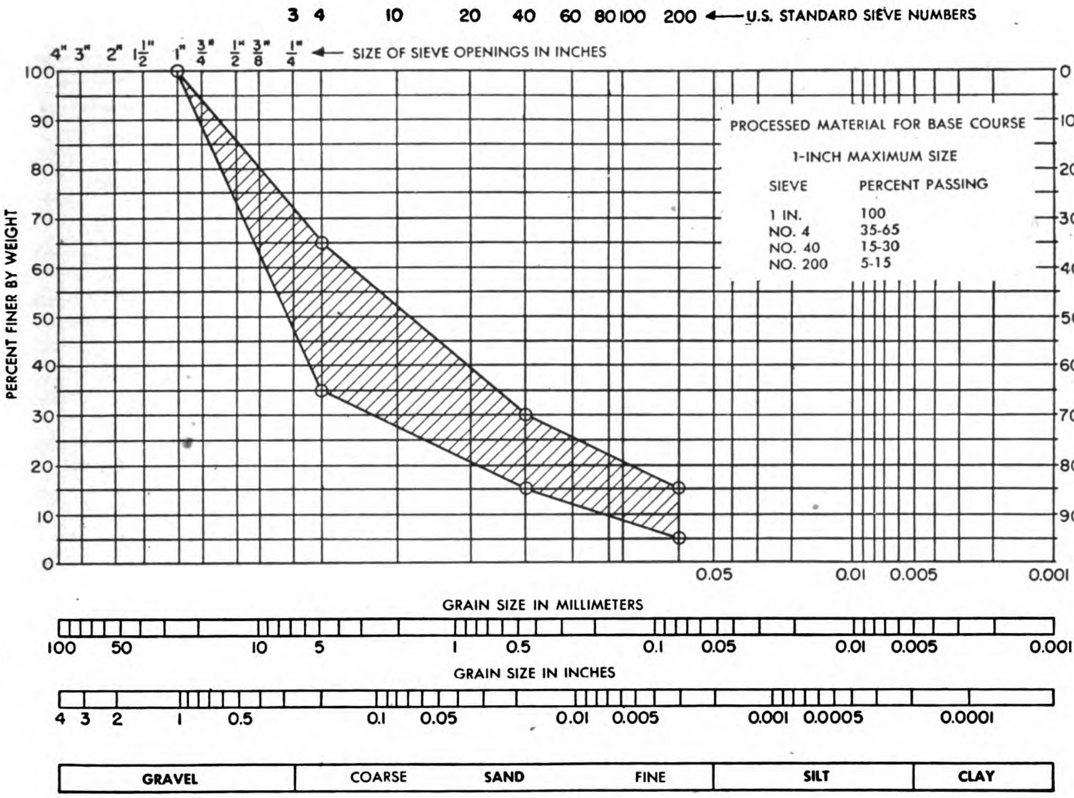


① *3-inch maximum size.*

Figure 33. Desirable gradation for processed base materials.



② *2-inch maximum size.*



③ *1-inch maximum size.*
Figure 33. Continued.

the subgrade. Where soil is used care must be taken to limit the amount of clay content, since too much clay is a serious defect that will destroy stability under moist conditions. Excess clay is indicated by a high plasticity index or linear shrinkage.

(2) GRADATION. Desirable gradations of composite material after blending are shown in figure 33 for 3-inch, 2-inch, and 1-inch maximum size material. Maximum particle size should not exceed three-fourths and preferably two-thirds the thickness of the base-course layer in which it is incorporated.

(3) PLASTICITY INDEX. Plasticity index requirements are the same as in **a**(3) above.

(4) STABILITY. Stability requirements are the same as in **a**(4) above and in table XII.

(5) BLENDING. To determine what fines and how much should be blended with the coarse aggregate a plot first is made of the sieve analysis of the coarse aggregate. A chart as shown in figure 33 is used. If the curve for the aggregate is outside the two limiting curves, a deficiency is indicated; if above, coarse material must be added; if below, fine material. The amount to add is estimated from the chart. Trial blends then are made, analyzed with sieves, and plotted. Those that are satisfactory are tested for compliance with plasticity-index and stability requirements.

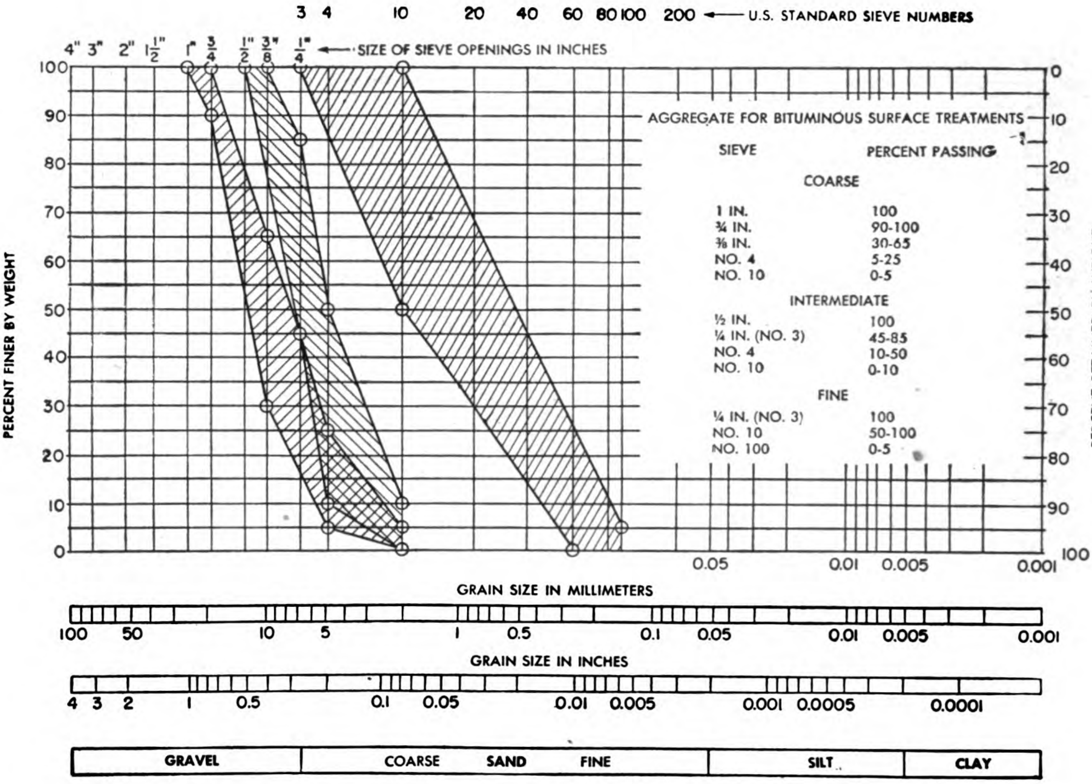


Figure 34. Desirable gradations for aggregate used in bituminous surface treatments.

c. Macadam aggregate. This is a processed material consisting of two sizes of clean, angular particles prepared by crushing and screening hard stone. Coarse aggregate is screened to pass a 3-inch sieve with not more than 15 percent passing a 1-inch sieve. Fine aggregate or screenings for dry-bound or water-bound macadam all should pass a ¾-inch sieve with not more than 25 percent of dust passing the No. 100 sieve. For bituminous penetration macadam the fine aggregate all should pass a ¾-inch sieve with not more than 25 percent passing the No. 4 sieve.

102. AGGREGATE FOR BITUMINOUS SURFACE TREATMENTS. Three sizes of aggregate—coarse, intermediate, and fine—may be used. Gradation requirements for each size are shown in figure 34. Particles must be sound and durable and free from loosely bonded coatings. Angular crushed particles are preferred for the coarse size. The intermediate size may be natural coarse sand or screenings. The fine usually will be clean sand.

103. AGGREGATE FOR BITUMINOUS PAVEMENTS. All aggregate particles should be sound and durable and free from loosely bonded coatings; however, material such as coral often is acceptable even though the particles are not strong as compared with sound gravel. The fraction passing the No. 200 sieve, called mineral filler, should be rock dust or similar inert fine soil; it should not contain an appreciable amount of clay (par. 96c). Gradation requirements are shown in figure 35 for 2-, 1-, ½-, and ¼-inch maximum size material.

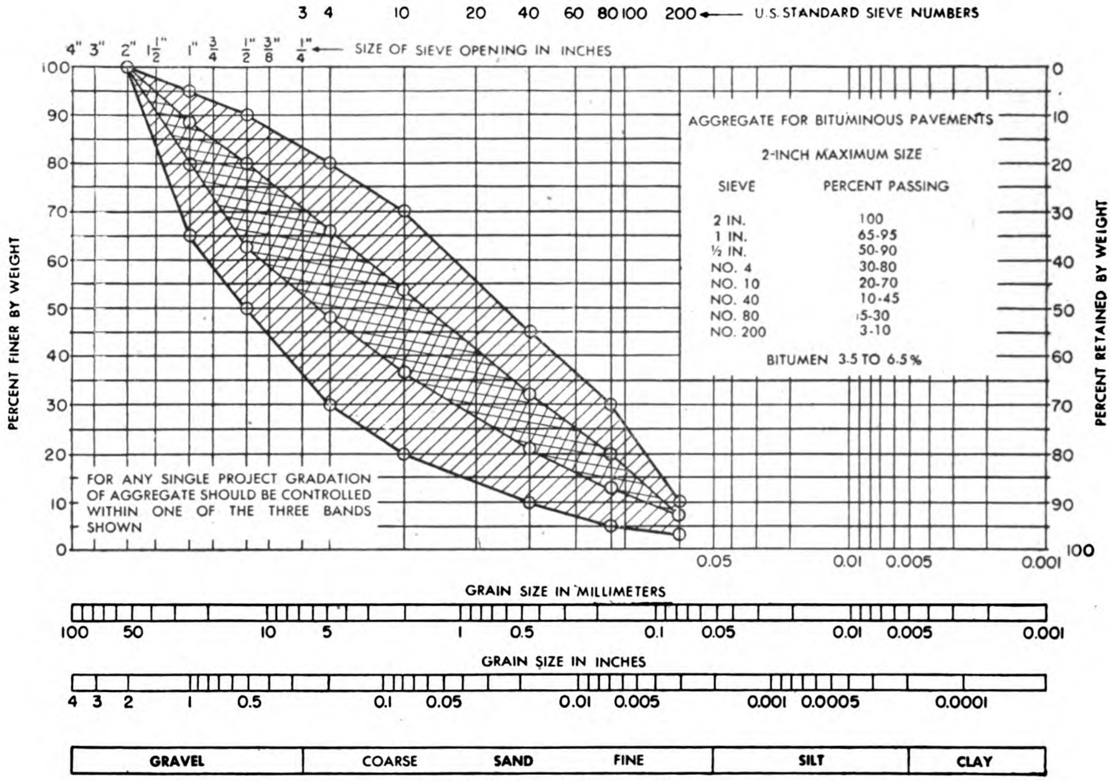
104. AGGREGATE FOR PORTLAND CEMENT CONCRETE. Coarse and fine aggregate for concrete construction must be composed of sound, durable, clean particles free from loosely bonded coatings. The fine aggregate (sand) may contain not more than 3 percent by weight of silt and clay and it must be free of organic matter. Dirty sand that otherwise is satisfactory may be cleaned by washing. Field tests for cleanliness and organic matter are given in paragraph 15, appendix III. Recommended gradation requirements are given in figure 36.

105. BITUMINOUS MATERIALS (ASPHALT AND TARS). The principal bituminous materials for airdrome construction are asphalt and tar products. Asphalt is derived from petroleum or from natural asphalt deposits, and tar from coal or from byproducts from the manufacture of gas. Both asphalt and tar consist principally of hydrocarbons called bitumen, and often they are designated by that name. They should not be mixed by blending in tanks or drums. However, they may be used in successive applications, such as in bituminous surface treatments, where a tar prime coat is followed by an asphalt binder coat. Each of these materials is available in several grades or forms convenient for various methods of construction. (See tables VII and VIII.)

a. Asphalt cement (AC). This is practically pure bitumen. At ordinary temperatures it is a semisolid. It is prepared in eight grades differing in consistency as measured by a standard penetration needle. Asphalt cement of 40–50 penetration grade is quite hard; 150–200 penetration asphalt is quite soft. To make this material sufficiently fluid to mix with aggregate, or to spray by distributor, it must be heated to a temperature between 250° and 350°F. When it cools it goes back to its original semisolid form.

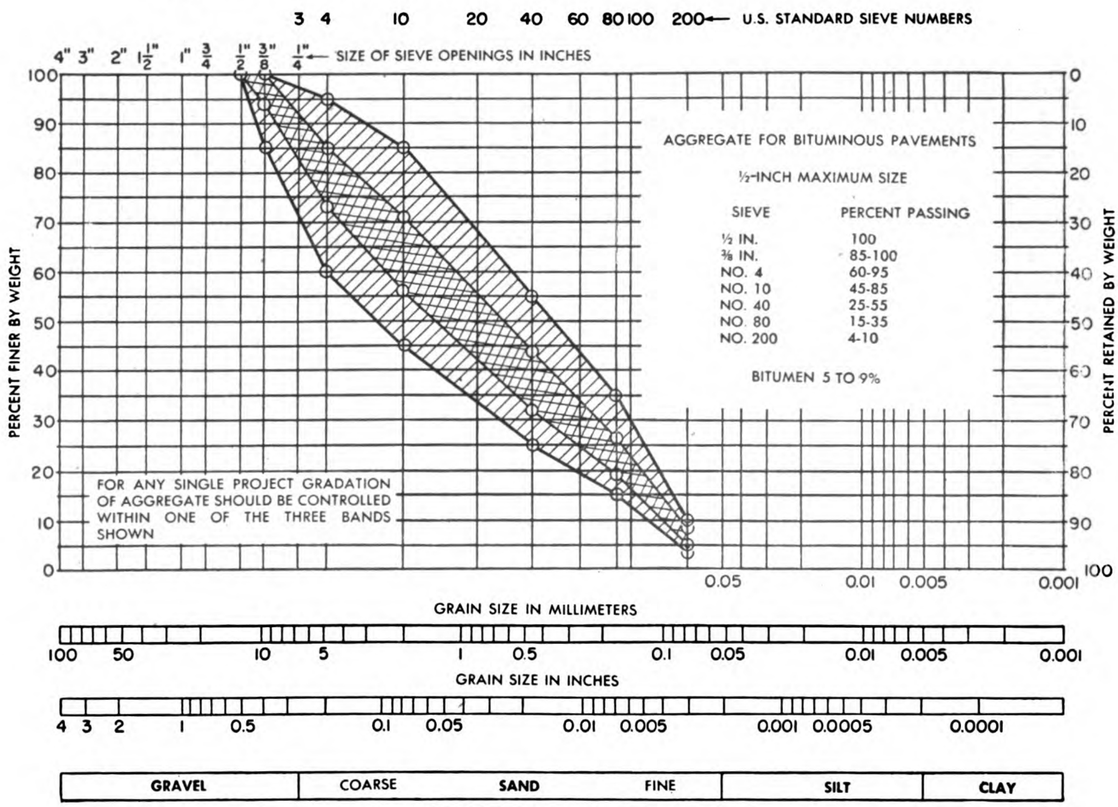
b. Slow-curing (SC) cutback asphalt. This is asphalt cement combined with slowly volatile petroleum oils similar to furnace oil. The oil dissolves the asphalt cement. The process is described as cutting back or thinning and the thinned material is called "cutback asphalt." Slow-curing cutbacks are prepared in six grades, SC–0 through SC–5 (table VII). In some localities an additional grade, SC–6, is manufactured. SC–0 contains about 50 percent asphalt cement and is fluid at ordinary temperatures. SC-5 contains about 80 percent asphalt cement and is thick and sticky at ordinary temperatures. The proportion of asphalt cement to cutback fluid gradually increases in the grades between SC–0 and SC–5.

c. Medium-curing (MC) cutback asphalt. This is asphalt cement combined with a volatile petroleum distillate similar to kerosene. It is prepared in six grades, MC–0 through MC–5. Each grade contains about the same percentage of asphalt cement as the corresponding grade of SC.

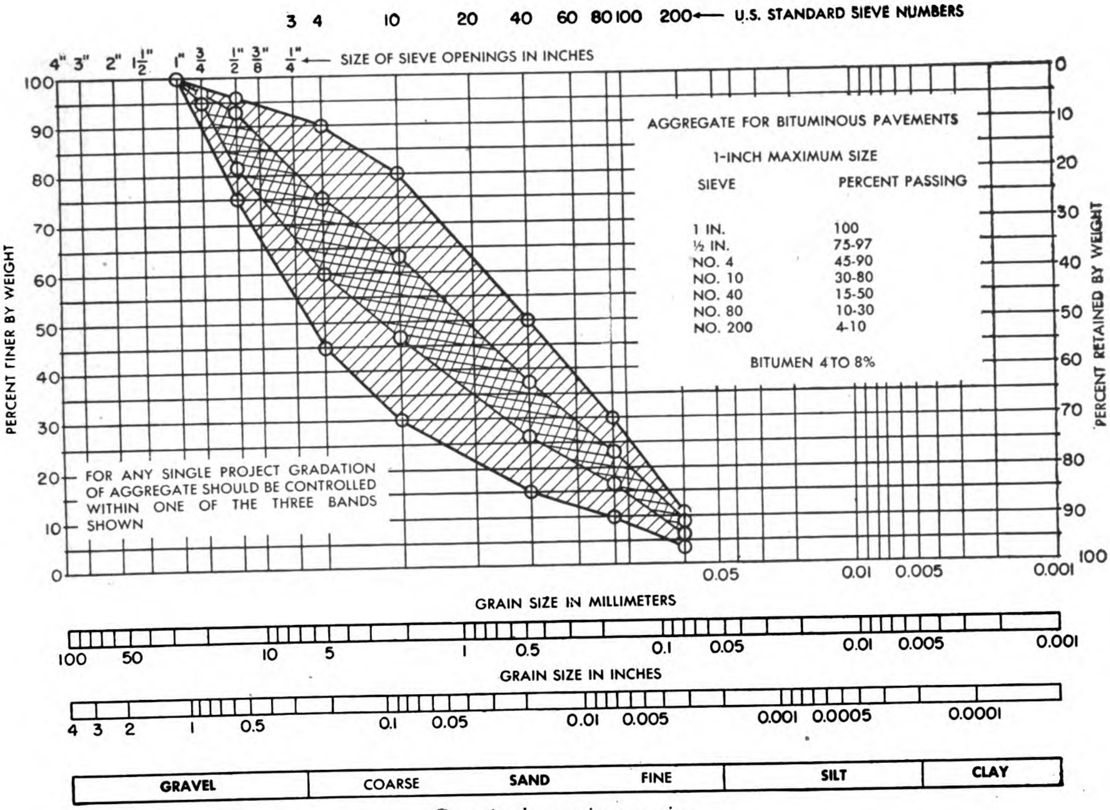


① *2-inch maximum size.*

Figure 35. Desirable gradations for aggregate for bituminous pavements.

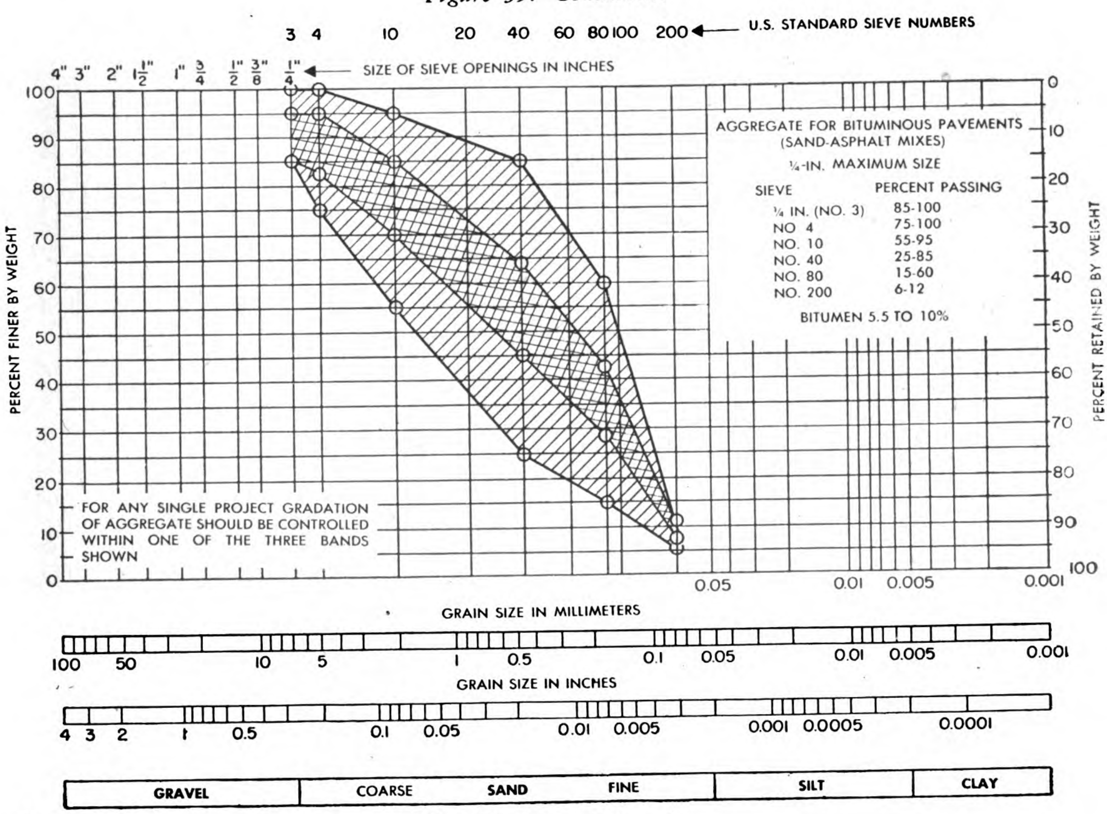


③ *½-inch maximum size.*



② *1-inch maximum size.*

Figure 35. Continued.



④ *¼-inch maximum size.*

Table VII. Bituminous materials.

Material	Source	Form	Grade designation	Temperature of application °F.	Remarks
Cutback asphalts (RC and MC).	Product of refining crude petroleum oils containing asphalt.	Liquids-asphalt residues fluxed with more volatile petroleum distillates.	Rapid Curing		Naphtha (highly volatile), evaporating quickly, leaving asphalt cement binder, permits early use of surface. Inflammable. Keep open flame away from storage tanks and drums.
			RC–0 –1 –2 –3 –4 –5	50°–120° 50°–120° 100°–175° 150–°200° 175°–250° 175°–250°	
			Medium Curing		Kerosene (less volatile) does not evaporate so quickly and cures more slowly than RC types. Inflammable. Keep open flame away from storage tanks, drums.
			MC–0 –1 –2 –3 –4 –5	50°–120° 80°–125° 150°–200° 175°–250° 175°–250° 200°–275°	
Asphalt road oils (SC).	Product of refining crude petroleum oils containing asphalt.	Liquids-low volatile oils left or blended with asphalt residues near end of refining process.	Slow Curing		Slow curing.
			SC–0 –1 –2 –3 –4 –5 –6	50°–120° 50°–120° 120°–180° 175°–250° 200°–275° 200°–275° 250°–300°	
Asphaltic cements (AC) or paving asphalts.	Product of refining crude petroleum oils containing asphalt.	Semiliquids or solids.	40–50 50–60 60–70 70–85 85–100 100–120 120–150 150–200 *	250° to 350°	Penetrations 40 to 100 used for crack and joint fillers. Penetrations 70 to 200 used for plant mixes penetration macadam, and surface treatment.

Powdered asphalt (PA).	Product of refining crude petroleum oils containing asphalt.	Hard and solid asphalts ground to powder.			Used with SC oils to produce extra tough road surfaces.
Asphalt emulsions (AE).	Asphalt cements in water with an emulsifying agent.	Liquids	Rapid, Medium, and Slow Setting		
			RS- 1	60°–120°	Freezing destroys emulsion, penetration and surface treatments.
			MS- 1 - 2 - 3	60°–120° 60°–120° 60°–120°	Road and plant mixes with coarse aggregate.
			SS- 1 - 2	50°–120° 50°–120°	Road and plant mixes with fine aggregate.
Road tar (RT) priming oils.	All road tars are products of coking bituminous coal.	Liquids	RT- 1 - 2 - 3	60°–125° 60°–125° 80°–150°	Waterproofs surfaces preparatory to placing other bituminous surfaces.
Cold tars (TC).	All road tars are products of coking bituminous coal.	Liquids	RT- 4 - 5 - 6 - 7	80°–150° 80°–150° 80°–150° 150°–225°	Road mixing and patching.
Hot tars (TH).	All road tars are products of coking bituminous coal.	Nonliquids	RT- 8	150°–225°	Patching and seal-coats.
			- 9 -10 -11	150°–225° 175°–250° 175°–250°	Plant mix and seal-coats
			-12	175°–250°	Penetration macadam.
Cutback tars (RTCB).	Tars combined with volatile distillates from coal or watergas tar.	Liquids	RTCB- 5 6	60°–120° 60°–120°	Patching mixtures. Inflammable. Keep open flame away from storage tanks or drums.
Rock asphalt.	Natural combinations of asphalt with sand or stone.	Solids			Mined and used locally where found.

* Penetrations of 100, 120, 150 and 200 show increasing softness or fluidity. Penetrations of 85, 70, 60, 50, 40, etc., show increasing hardness of solidity. Road oil SC–6 (with high viscosity) and the softest paving asphalts both have penetrations of about 200.

*Table VIII. Typical uses of bituminous materials for average fair-weather construction.**

Purpose or use	Grade or designation					
	RC Rapid curing	MC Medium curing	SC Slow curing	AC Asphalt cement with penetration of:	AE Asphalt emulsion	RT—Road tar RTCB—Road tar cutback
Dust palliative	....	MC–0–1–2	SC–0–1–2	....	....	RT–1
Prime coat*:						
Tightly bonded surfaces	....	MC–0	SC–1	....	....	RT–2
Loosely bonded fine-grained surfaces	....	MC–1	SC–2	....	....	RT–3
Loosely bonded course-grained surfaces	....	MC–2	....	....	....	RT–4
Tack coats	RC–2, 3, 4	....	....	....	RS–1	RT–4, 5, 6, 7, 8, 9
Surface treatment and seal coats:						
With or without light sand cover	RC–1	....	....	....	RS–1	RT–6, 7, 8, 9, 10
Coarse sand cover	RC–2	MC–2, 3	....	....	RS–1	
Clean coarse aggregate cover	RC–2, 3, 4	MC–3, 4	....	150–200	....	
Graded gravel aggregate cover	....	MC–2, 3	SC–3	....	....	
Gravel mulch	....	MC–2	SC–2	....	....	
Mixed in place—Road mix:						
Open-graded aggregate:						
Sand	RC–1–2	MC–3	....	....	....	RT–6
Maximum diameter 1 in., high percentage passing 10 mesh	....	MC–3, 4	....	....	MS–1	RT–6
Macadam aggregate	RC–2–3	....	....	....	MS–1	RT–7
Dense-graded aggregate:						
High percentage passing 200 mesh	....	MC–2	SC–2	....	SS–2	RT–4–5
Maximum diameter 1 in., medium percentage passing 200 mesh	....	MC–2–3	SC–2–3	....	SS–1	RT–5–6
Premix or cold patch:						
Open-graded aggregate	RC–2	MC–3	SC–3	....	MS–3	RT–5, 6, 7, 8 RTCB–5, 6
Dense-graded aggregate	....	MC–2	SC–2	....	....	

Cold-laid plant mix:						
Open-graded aggregate:						
Sand	RC-2-3				MS-2	RT-5, 6, 7, 8, 9
Maximum diameter 1 in., high percentage passing 10 mesh	RC-3		SC-3		MS-3	RT-5, 6, 7, 8, 9
Macadam aggregate	RC-4-5					RT-5, 6, 7, 8, 9
Dense-graded aggregate:						
High percentage passing 200 mesh		MC-3, 4	SC-3, 4		SS-2	RT-5, 6, 7, 8, 9
Maximum diameter 1 in. medium percentage passing 200 mesh		MC-4	SC-4		SS-1	RT-5, 6, 7, 8, 9
Aggregate precoating followed with asphalt		MC-0	SC-1			RT-5, 6, 7, 8, 9
Hot-laid plant mix	RC-5	MC-5	SC-5, 6	85-150		RT-11, 12
Penetration macadam:						
Cold-weather	RC-5		SC-6	100-150	RS-1	RT-11
Hot-weather				85-100	RS-1	RT-12

* Prevailing temperature during construction also affects selection of grade of bitumen and may be the determining factor rather than size and gradation of aggregate.

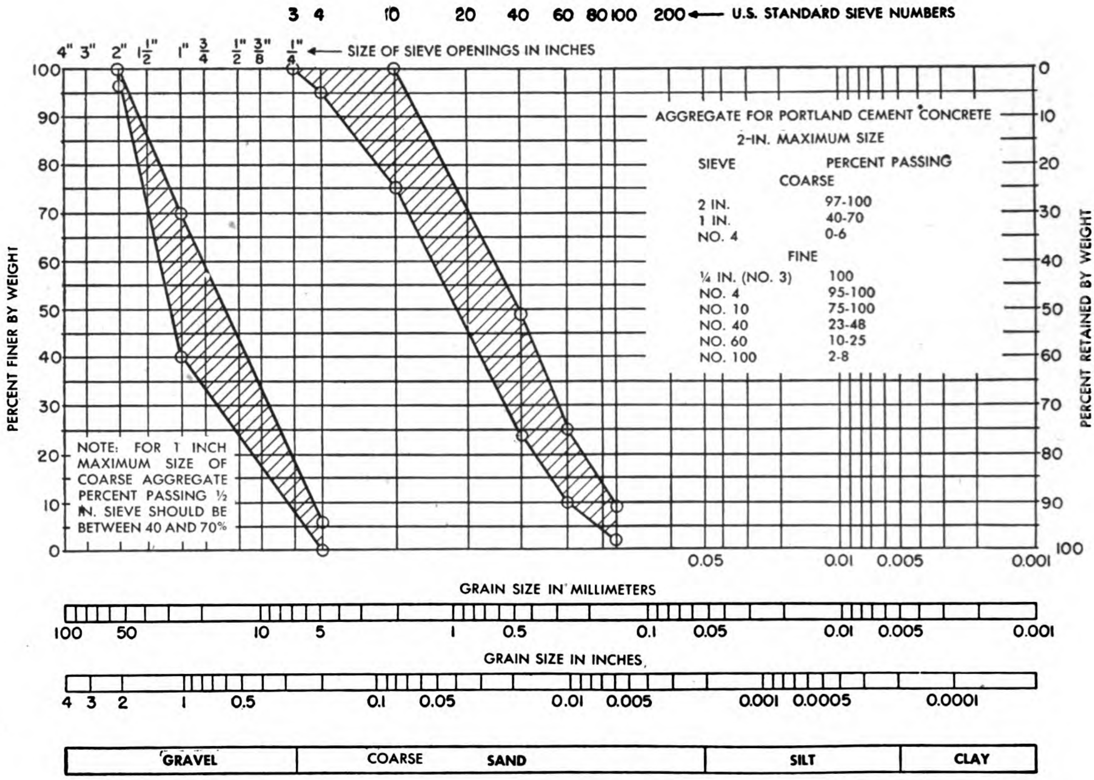


Figure 36. Desirable gradations of coarse and fine aggregates for portland cement concrete.

d. Rapid-curing (RC) cutback asphalt. This is asphalt cement combined with naphtha, a highly volatile petroleum distillate similar to gasoline. Otherwise RC's are similar to the SC's and MC's.

e. Uses of cutback asphalts. The various kinds and grades of cutback asphalt permit the use of a variety of methods and equipment under various construction and weather conditions, utilizing nearly any kind of local aggregate. The essential ingredient in cutbacks is the asphalt cement. After the cutback is sprayed on a base, or mixed into an aggregate on a runway, the solvent evaporates leaving the asphalt cement as the active binding and waterproofing agent. This process is known as curing. Table VIII shows typical uses of bituminous materials for various types of construction and kinds of aggregate. Prevailing atmospheric temperature during construction is another factor that must be considered in selecting the grade of cutback. For example, where MC-1 would be used as a dust palliative on a particular base in hot weather MC–0 would be used in colder weather. Similarly, where MC–3 would be used for mixed-in-place construction in hot weather MC–2 would be better in cool weather.

f. Thinning cutbacks in the field. In the field it is not practicable to stock several grades of cutback. Any cutback can be thinned by adding and

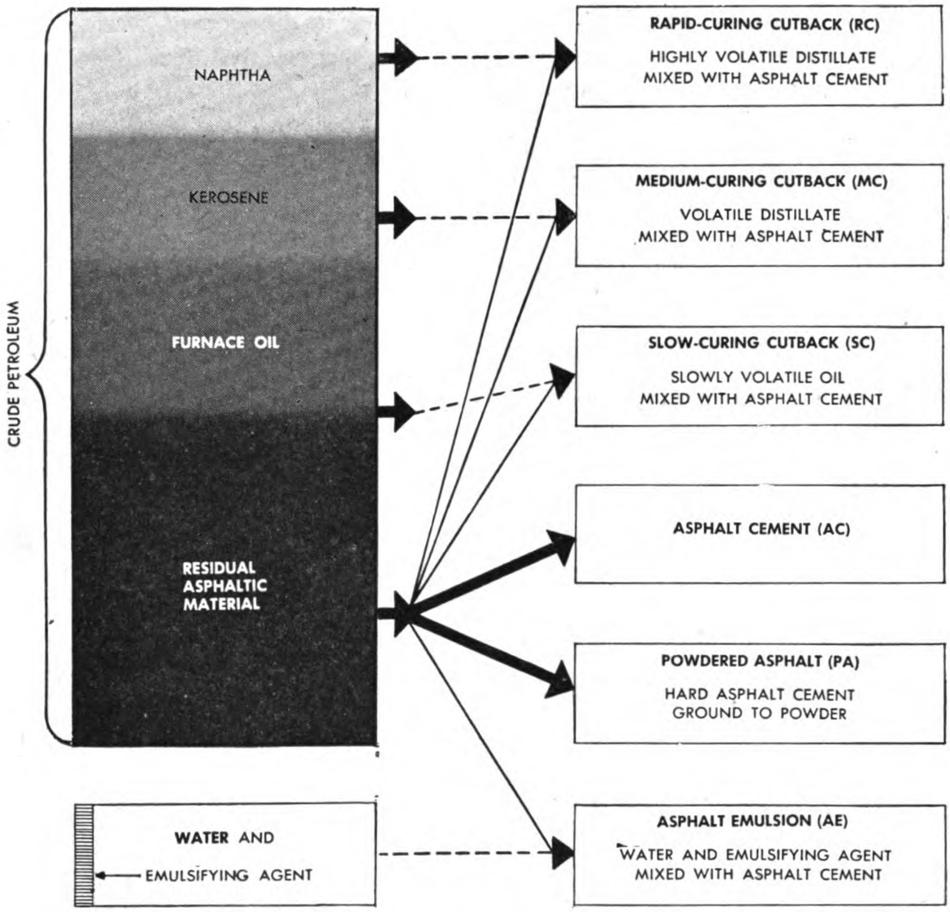


Figure 37. General make-up of petroleum asphalt products. (See table VII.)

mixing a petroleum solvent similar to the one used in original manufacture—gasoline for the RC's, kerosene for the MC's, and Diesel oil for the SC's. Small quantities may be thinned by mixing in drums. For larger quantities the distributor or the 1,500-gallon trailer tank may be used. In these, mixing is accomplished best by pump circulation. Hand-stirring with wood paddles may be used if necessary.

Caution: To avoid fires and explosions all cutbacks must be handled with extreme care when being heated. Open flames, lanterns, sparks, or fire of any kind must not be allowed near the domes of tank cars, or near manholes or other openings in the top of distributors or storage tanks, because of the danger of explosion of accumulated solvent vapors. All transporting and heating tanks must be vented against accumulated vapor pressure.

g. Asphalt emulsions (AE). These are mixtures of asphalt cement and water in about equal proportions. Bituminous materials ordinarily do not mix with water but, by the addition of a small amount of chemical (emulsifying agent), it is possible to effect a temporary mixture in the form of an emulsion. Asphalt emulsions are brown liquids. They can be sprayed and mixed with aggregate without heating. After spraying or mixing, the water and asphalt separate, the water evaporating to leave the asphalt cement. Asphalt emulsions are manufactured in three grades differing in the rate at which the asphalt and water separate upon use.

(1) Rapid-setting, RS–1.
(2) Medium-setting, MS–1, MS–2, MS–3.
(3) Slow-setting, SS–1, SS–2.

Caution: Freezing damages asphalt emulsions.

h. Tars. Tars are somewhat similar to asphalts in form and use. Road tars (RT) are manufactured in twelve grades, RT–1 through RT–12, differing in fluidity (table VII). RT–1 is similar in fluidity to SC–1; RT–12 is semi-solid. Road-tar cutbacks (RTCB) are tars combined with liquid coal distillates. They are inflammable and must be handled with the same precautions as cutback asphalts.

i. Manufacture. Figure 37 illustrates the general manner in which asphaltic products are manufactured from crude petroleum.

j. Shipping. Bituminous material is shipped in various ways. Barrels may be used for hard asphalt cement. Steel drums of 55-gallon capacity may be used for any bituminous material. Except for emulsions and highly fluid products, heating is necessary to empty the drums. The 1,500-gallon trailer with steam coils (fig. 229) is provided for this purpose. Bituminous materials also may be shipped in bulk by tanker, barge, railroad tank car, or tank truck. For short hauls the tanks may be insulated to keep the material hot and fluid for pumping. If not unloaded before cooling, the tank must be equipped with steam coils for reheating at the unloading point.

106. PORTLAND CEMENT. Standard portland cement is used for concrete construction. Generally it is delivered in cloth or paper bags ready for use. Each bag contains 94 pounds of cement and has 1 cubic foot loose volume. High-early-strength cement is similar to standard portland cement except it hardens and develops strength much faster. The barrel frequently is used as a unit of measure for cement. It is equivalent to four bags, or 376 pounds of cement.

Caution: Cements must be kept dry until used.

107. DUST PALLIATIVES. In addition to bituminous products (table VII), various other materials may be used to allay dust on landing strips, taxiways, and roads.

a. *Crude petroleum* is used in the same manner as cutback asphalts (par. 143).

b. *Calcium chloride* in flake form is shipped in waterproof bags. This material has the property of absorbing moisture from the air if the humidity is not too low. It is not effective in arid or semiarid conditions. When spread on a landing-strip surface it attracts moisture which settles the dust. Being soluble in water it is carried away by rain water and must be reapplied at intervals.

Caution: Small quantities of calcium chloride do not promote corrosion of metal, but it should be used at airdromes only with air force approval.

c. *Ordinary salt* (sodium chloride) dissolved in water, or sea water, sprinkled on a runway, settle dust to some extent, but are not as effective as calcium chloride. Their use, however, is subject to the same caution.

d. *Lignin solution,* a liquid waste from pulp (paper) plants, may be used as a dust palliative if it is conveniently available. It corodes metal unless neutralized by adding lime.

e. *Molasses* diluted with water may be used as a dust palliative where it is conveniently available.

f. *Turf* or other vegetation spread on the surface or disked into the soil provide an effective dust palliative.

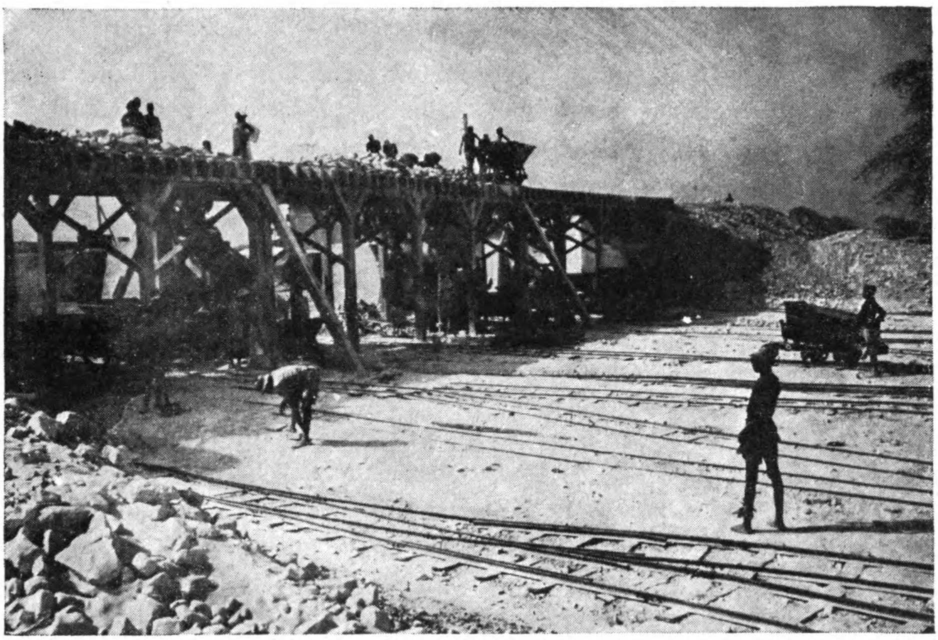


Figure 38. Existing quarry and crushing plant used in airdrome construction.

108. PROSPECTING FOR ROCK AND AGGREGATE. a. Obvious sources. Existing developed pits and quarries (fig. 38), stream beds and banks, beaches, mine dumps, outcrops, and banks exposed in road or railroad cuts are the obvious sources to be investigated first. Their locations should be plotted on a map for comparative haul studies and to serve as an inventory of available sources.

b. Concealed sources. Some regions have deep mature soils, as in Burma, or mantles of glacial drift, as in northern Europe, which conceal the underlying gravel or bedrock. In such areas the best guides for prospecting are topography, composition of surface soils, and vegetation.

(1) TOPOGRAPHY. In a relatively flat plain or a region of deep surface soils the most favorable places to find materials are at high points or in stream channels. In glaciated areas the rounded ridges and the areas on the downstream side of lakes are likely sources of granular material.

(2) VEGETATION. In most regions the character of vegetation indicates the nature of the underlying soil. However, since plant growths differ among regions, to interpret the relationships between vegetation and soil types each region must be studied separately. For example, in western United States mesquite favors a clay or silt soil, conifers prefer sandy or gravelly soils, and certain types of cedar prefer calcareous soils.

(3) SOIL TYPES AS INDICATORS OF UNDERLYING FORMATIONS. Soils overlying sandy and gravelly formations commonly contain at least small proportions of sand and gravel. Loose sandy soils overlie beds of sand, sandstones, sandy clays or shales, or granitic rocks. Clay soils overlie limestones, beds of clay, shales, fine-grained igneous rocks, and certain types of schists and slates.

109. ESTIMATING QUANTITY IN A DEPOSIT. a. Sand and gravel. The yardage available in a deposit is estimated by determining the thickness of the bed and multiplying it by the horizontal area covered. For example, if a gravel bed in a terrace has an outcrop 3 yards thick and 300 yards long, and if the bed is 100 yards wide from the exposed edge back to the foot of the higher slope, the total quantity of gravel which may be expected is about 90,000 cubic yards. Excavation may reveal an additional thickness of gravel below the visible exposure. For proper measurement of the horizontal area of the bed, lines of holes deep enough to reach the gravel should be bored on about 200-foot centers. Alternate holes should penetrate the gravel deposit 3 or 4 feet if possible. The borings yield information on thickness of overburden and quality of the gravel. Complete records of each boring should be kept. If outcrops are absent the deposit must be prospected entirely by borings or dug test pits. Test pits should be large enough in diameter for a man to work in the hole and deep enough to prove a usable thickness of material. In loose material shoring is used to prevent caving.

b. Ledge rock. In prospecting consolidated rock formations for crushable rock, the exposed edges and the horizontal extent are measured as for gravel beds. Test borings are made to measure thickness of overburden.

110. EVALUATION OF MATERIAL FROM PITS AND QUARRIES. Materials available in pits and quarries are evaluated by inspection and trial of representative samples, supplemented by laboratory examinations. (See par. 2, app. III, for sampling methods.) Before deciding the runway design and construction procedure to be employed it is necessary to know all characteristics of the available materials. Where more than one source of material is available they should be compared as to quality of material, runway design best suited to each, and equipment and construction time required. This study is the basis for deciding the method of extracting and the plant and equipment requirements for processing. For efficient operation it is necessary to select the right kind and size of equipment items.

a. Ledge rock. (1) GENERAL. The most important features to observe in evaluating bedrock for crushing are—

Degree of weathering.
Number, arrangement, and spacing of joints.
Composition of the rock.
Texture—grain size and range of grain.
Bedding—thickness and variations.
Veins and dikes.
Hardness and degree of cementation.

(*a*) The degree of weathering is one of the most important features to be considered in the use of bedrock for base-course or concrete construction, especially in igneous rocks. Badly weathered rock often has clay and related minerals in such proportion that it is unsatisfactory for construction purposes. Fresh igneous rocks have about the same cohesion throughout, while weathered rocks frequently are soft and crumbly.

(*b*) The number and spacing of joints are important because they influence the method of quarrying. If large blocks for masonry construction are not desired, close spacing of joints or cracks in a rock formation is desirable because quarrying and crushing of the smaller pieces is easier.

(*c*) Thicknesses and variations in bedding should be considered because many sedimentary rock formations contain beds of soft or otherwise undesirable rock.

(*d*) Special caution should be used in studying degree of hardness especially in sedimentary rocks such as sandstone or limestone. Some outcrops have developed case-hardened surfaces much harder than the main body of the rock. Samples for study should be taken from the fresh surface after breaking through the case-hardened surface.

(2) EXAMINATION FOR QUALITY. Ledge rock is examined primarily for hardness and crushing characteristics. Trial crushing is desirable, but breaking by hand hammering discloses essential information on ease of fracture and character of the crushed product. Hard rock usually requires a plant with primary and secondary crushers to produce an aggregate with proper gradation and sufficient fines. A soft rock may be processed by a single jaw or roll crusher. Rock quarries containing seams of dirt and clay may yield a product too high in fines unless measures are taken to exclude the clay in quarrying. Following are general evaluations of commonly used rock.

(*a*) *Trap rock* (basalt) possesses all the necessary qualities as aggregate for a base course, for bituminous construction, and for concrete.

(*b*) *Granite* is hard if unweathered, but lacks cementing value. Selected fines usually must be added when it is used for a base course. It is suitable for bituminous construction and concrete. Weathered or disintegrated granite is soft and crushes easily. Sometimes it can be reduced by light blasting and excavating machinery. Disintegrated granite is variable in character and in the quantity of clay it contains. Ordinarily it is good base material but it must be checked for clay content. Its use as aggregate for bituminous mixtures also is subject to this precaution. It should not be used for concrete.

(*c*) *Limestone* is brittle and somewhat softer than trap rock but has high cementing value. It is satisfactory for base courses, for bituminous mixtures, and for concrete. Some varieties of limestone are too soft to be used as cover aggregate for bituminous surface treatments.

(*d*) *Shale* usually is soft. Weathered shale frequently contains excessive clay which is detrimental in base courses. Some hard shales produce satisfactory aggregate if not too laminated.

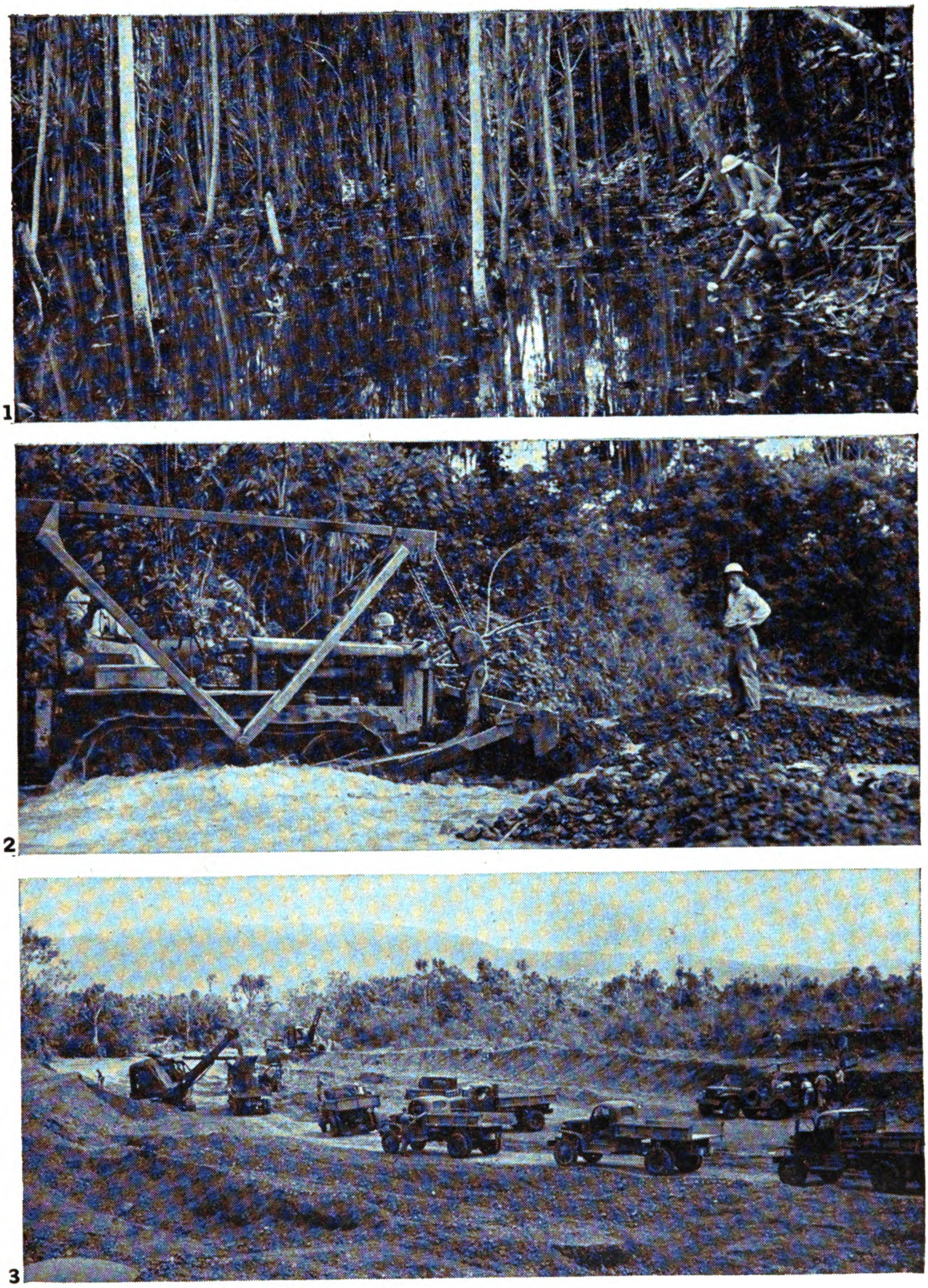
(*e*) *Coral* is found in a variety of shapes and structures. Some common ones are tree coral, finger coral, and ledge coral. This material is recovered from the sea by dredge or dragline, or from ledges on land that has been pushed up from the sea by geologic processes. Coral generally is soft and easily compacted into a satisfactory base course. When crushed, screened, and washed the harder forms of coral are suitable for bituminous mixtures. With extra cement they may be used for concrete aggregate, but other hard aggregate is preferable.

b. Gravel-sand deposits. Beds, banks, and bars of gravel-sand are examined for gradation and quality of particles, especially the fines passing No. 40 and No. 200 sieves. These sources usually contain rounded particles, hence, when used for a base course, stability depends upon good gradation and correct quality and proportion of binder (par. 96). The plan for using a deposit must be framed with this requirement in mind. If a deposit contains too much dirt and clay, provision must be made to remove the excess in the processing plant. Deposits that lack fines require blending. This may be done by adding fines at the processing plant or on the runway.

c. Filler or soil binder. Filler or soil binder, for blending with coarser aggregate, is tested in combination with it.

111. OPERATING PITS AND QUARRIES. a. Planning and lay-out. The selected site should be studied carefully with the view of taking full advantage of topography for gravity flow of materials. A scale lay-out is useful for planning the plant set-up to provide drainage at all times and to give sufficient working space and stock-pile storage without excessive material handling. A drive-through arrangement for trucks hauling to or from the plant generally is better than one which requires backing in to load or unload. Ramps are useful for trucks or dozers delivering material to hoppers or loading traps.

b. Development. Once the plan for operating the pit or quarry is decided, the preliminary work of developing the site is undertaken. Usually this includes building roads to the site, stripping the overburden, preparing and draining the working area, and setting up the plant. Stripping includes clearing and removal of roots (fig. 39).



① *The undeveloped site.*

② *Diverting stream and stripping of overburden.*

③ *The pit in full-scale operation.*

Figure 39. Developing a gravel pit.

Figure 40. Gravel pit stripped and ready for production. Note loading trap.

If the material has natural cementing character, like coral, shell, or limerock, all foreign material should be excluded so as not to destroy or lessen such qualities. This requires careful removal of all overburden before mining operations begin. However, if material such as gravel or sand-clay is used, a small amount of overburden may be desirable rather than harmful.

c. Recovery. The method of removing or mining a deposit varies with the character of the material and with site conditions. In soft or loose materials scrapers, dozers, power shovels, or draglines may be used (fig. 40). In dense compact material loosening may be done with a tractor-drawn rooter. Light jarring shots with explosives may be helpful. Hard material must be blasted. Depending upon the character of the material, blasting may reduce it in size so that it can be used as base without processing in a plant.

Figure 41. Quarry operations using local labor.

d. Quarrying (figs. 41 and 271). In working a cliff of rock for quarry purposes the spacing and location of holes and powder charges are carefully planned to get the maximum shattering effect. Table IX gives suggestions for trial shots. As quarrying operations progress these are adjusted as indicated by experience. Seamy or laminated deposits of rock may be broken up or shattered better by using the coyote-hole method. Coyote holes are made by drilling or digging horizontally instead of vertically. Staggered drill holes driven vertically with air hammers usually are more effective in monolithic deposits. In working such deposits it may develop that, after the quarry site is opened, better stone is obtained by working the quarry floor down rather than continuing to work back on the cliff. This gains greater shattering effect from the powder and usually the stone in such deposits shatters better at the lower strata than at the surface. However, in using this method consideration must be given to the need for and method of draining the quarry.

TABLE IX. Trial charges and drill-hole spacing for quarrying operations.

Type of material	Spacing of drill holes: Along rows	Spacing of drill holes: Between rows	Depth of hole	Amount of explosive per cu. yd. of burden (pounds)	Recommended explosives (or equivalent)
Rocks exceptionally difficult to shatter.	$1/2d$	$1/2d$	$d+2$	¾ to 1	Gelatin or 60 per cent straight dynamite.
Hard, dense, unweathered (ledge) rock.	$2/3d$	$2/3d$	do.	¾ to 1	Gelatin or 50 per cent straight dynamite.
Medium hard, weathered, or partly disintegrated rocks, those which shatter readily, and extremely hard shales.	$3/4d$	$2/3d$	do.	½ to ⅝	Gelatin or blasting powder if holes are dry; or, 40 per cent straight dynamite.
Ordinary shale, cemented clay and gravel, and similar material.	$1\frac{1}{4}d$	d	do.	½ to ⅝	Gelatin or blasting powder if holes are dry; otherwise, 20 per cent straight dynamite.

NOTES

d is distance from existing surface to desired grade or face of wall.
Holes may be either vertical or horizontal.
Charges do not include springing charges.
Data are based on holes 5 to 25 feet deep.
Volume of burden per hole is equal to depth of hole times spacing along rows times spacing between rows.

Loose material should be scaled from the quarry face, starting from the top and working down. Avoid having men work one above another. Close supervision should be given drilling to get maximum production. Points to check are—

(1) Volume and pressure of air.
(2) Blowing and cleaning of holes.
(3) Leaks in air line and connections.
(4) Crowding of drills.
(5) Condition of bits.
(6) Loss of time in changing bits or steel.

e. Processed materials. Equipment for crushing, screening, or washing aggregate is described in paragraph 205. The 150- and 100-ton per hour plants are composed of units as listed in table XXXVIII. Variation to suit local conditions is made by combining the units in different ways. Where crushers only are used and the pit or quarry is nonuniform, it is necessary to regulate and balance the material fed into the plant so the product will be uniform as to grading and amount of fines. Care in this operation may save blending and mixing on the runway.

f. Inspection. The material from processing plants should be given continuous inspection with special attention to gradation and character of the fine fractions passing the No. 10, 40, and 200 sieves. Where materials contain clay, visual inspection is not adequate. The inspector should be equipped with sieves and other necessary apparatus, taken from the laboratory set or improvised to make periodic tests, to confirm visual inspection. (See par. 133 and app. III.)

CHAPTER 13

CLEARING, GRADING, AND DRAINING

112. SCOPE. This chapter deals with the clearing, grubbing, grading, and draining involved in the construction of an airdrome. Emphasis is placed on the use of aviation engineer equipment rather than upon hand methods. Both standard and alternate proved construction methods are detailed. In addition, there are many innovations which may be employed in emergencies. Versatility and ingenuity are required to get the best results with available equipment and under varying operating conditions.

113. CONTROL OF WORK. Speed is gained by utilizing under continuous supervision all available men and equipment to execute a well-thought-out plan, which anticipates and provides for overcoming difficulties and assures that materials and supplies will be available when and where needed.

114. CONSTRUCTION SURVEYS (see TM 5–235). **a**. To prevent delay and waste effort, adequate stakes must be set by survey well in advance of construction. Necessary construction stakes (fig. 42) and their order of placement are as follows:

(1) Alignment stakes, at 100-foot intervals, which define the center line and shoulder lines or edges of landing strips. Shoulder-line stakes need not be placed on taxiways and roads less than 50 feet wide.

(2) Slope stakes, usually at 100-foot intervals and at sharp breaks in the ground profile. These stakes define the limits of grading work and the areas of clearing and grubbing. Numerals on the face of the stake indicate the amount of cut or fill at the location of the stake in relation to the grade elevation at the center line opposite the slope stake.

(3) Finish-grade stakes (or blue tops), usually at 100-foot intervals on shoulder lines and center line, to control finished work accurately.

b. A notebook is kept containing a record of stakes placed and information relating to them. Stakes knocked out or demolished by construction equipment readily can be replaced from this information. Forms for note keeping may be found in TM 5–235.

115. CLEARING AND GRUBBING. a. General. Clearing and grubbing consists of removing trees, stumps, brush, logs, windfalls, other vegetation, and boulders from areas to be occupied by landing strips, taxiways, hard stand-

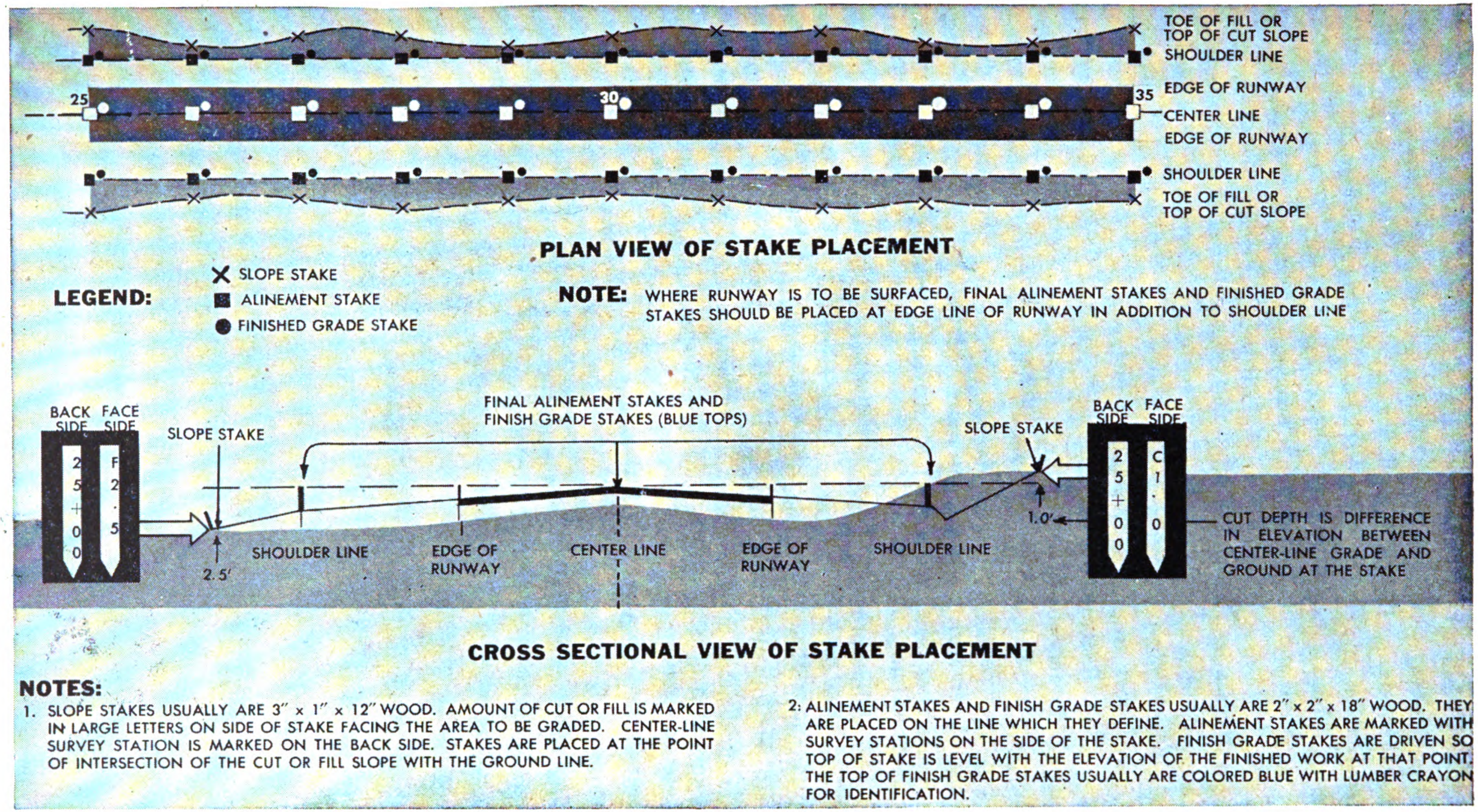


Figure 42. Schematic diagram showing placement of alignment stakes, slope stakes, and finish-grade stakes.

ings, roads, buildings, and other facilities. Clearing is held to the minimum to avoid unnecessary work and to preserve all natural ground cover.

b. Methods. (1) Light vegetation is burned, cut by mower or by hand, or removed by dragging a heavy steel rail, I-beam, or similar piece of metal crosswise behind a tractor or truck.

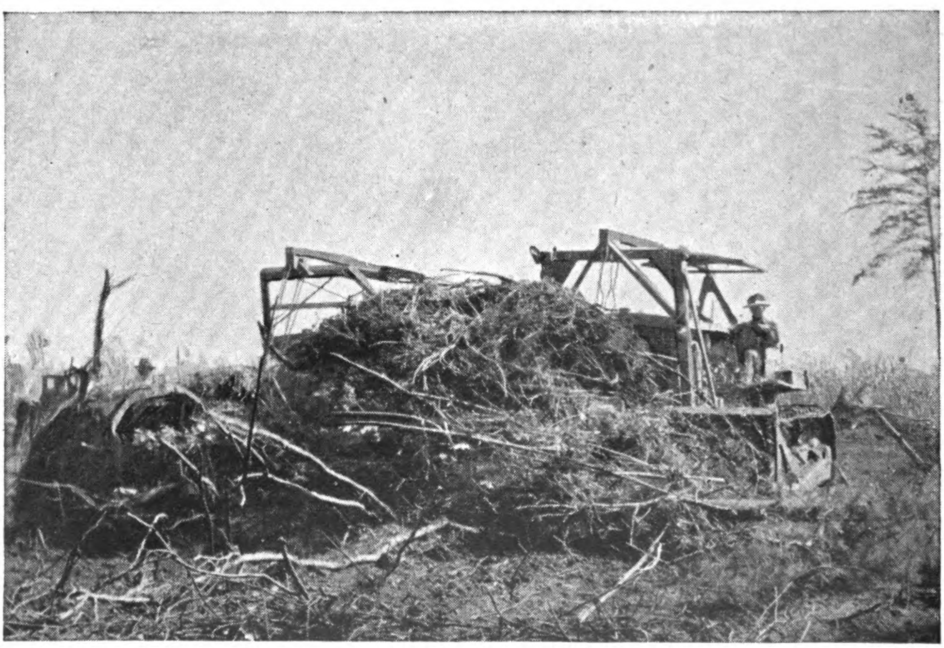
(2) Sagebrush and similar vegetation may be cleared by motor grader or dozer (fig. 43).

(3) Small trees are cleared by cutting with axes, hand or power saws, or with dozers. Small trees and low bushes may be removed by dragging a wire rope stretched between two tractors.

(4) Large trees are felled by cutting with saws (fig. 44) or by explosives (FM 5–25). Roots should be removed to at least 9 inches below subgrade elevation. In areas to be covered with fill the stumps need not be grubbed if their tops are at least 1 foot below subgrade. Where necessary, stumps are grubbed by winches, by explosives (FM 5–25), or by a combination of the two. The angledozer, with blade straight and raised, may be used to push out trees and stumps after blasting (fig. 45), or they may be pulled by the crawler type tractor.

Sometimes stumps or entire trees may be removed by the dozer without blasting or cutting (fig. 46). In difficult cases the first step is to make with the dozer a saucer-shaped excavation around the base of the tree on the side opposite to the fall, cutting small roots and obstructions. The second step is to make similar excavations on the two remaining sides other than the fall side. Dirt from all cuts then is pushed into the first and built into a ramp sloping up to

Figure 43. Clearing brush with pair of dozers.



the tree, enabling the dozer to gain leverage by pushing higher on the trunk. The final step is to push with the tractor, lifting up with the blade at the same time. As the tree falls the tractor quickly is backed up a few feet to be clear of roots which might high-center the tractor.

(5) Disposal of cleared material must conform to the camouflage plan. In general, the material is disposed of by—

(*a*) Piling and burning, when permissible and practicable.

(*b*) Moving it by tractor or dozer out of the construction area into adjacent woods (fig. 47). Timber useful for logs, poles, posts, piles, and lumber may be salvaged by trimming, disposing the slashings with smaller brush. Some of the cleared trees and brush may be useful for camouflage.

(6) Boulders are cleared by rolling or pushing with dozer (fig. 48) if ground permits, or by blasting large or deeply embedded ones (FM 5–25). Hand- or machine-loading into trucks also may be employed.

c. Rates of clearing are given in table XXVIII, chapter 21.

116. STRIPPING. **a.** Stripping consists of removing and disposing of topsoil and sod which would be objectionable as a foundation under a fill or as a subgrade material when incorporated in a fill. Material of this type is excavated and disposed of concurrently with clearing and grubbing. Stripped material may be used for covering bare areas for dust control.

b. The soil profile (par. 79) may indicate that stripping of topsoil and sod will uncover a subgrade material of sufficient strength when compacted to satisfy

Figure 44. Pneumatic chain saw used in tree clearing.

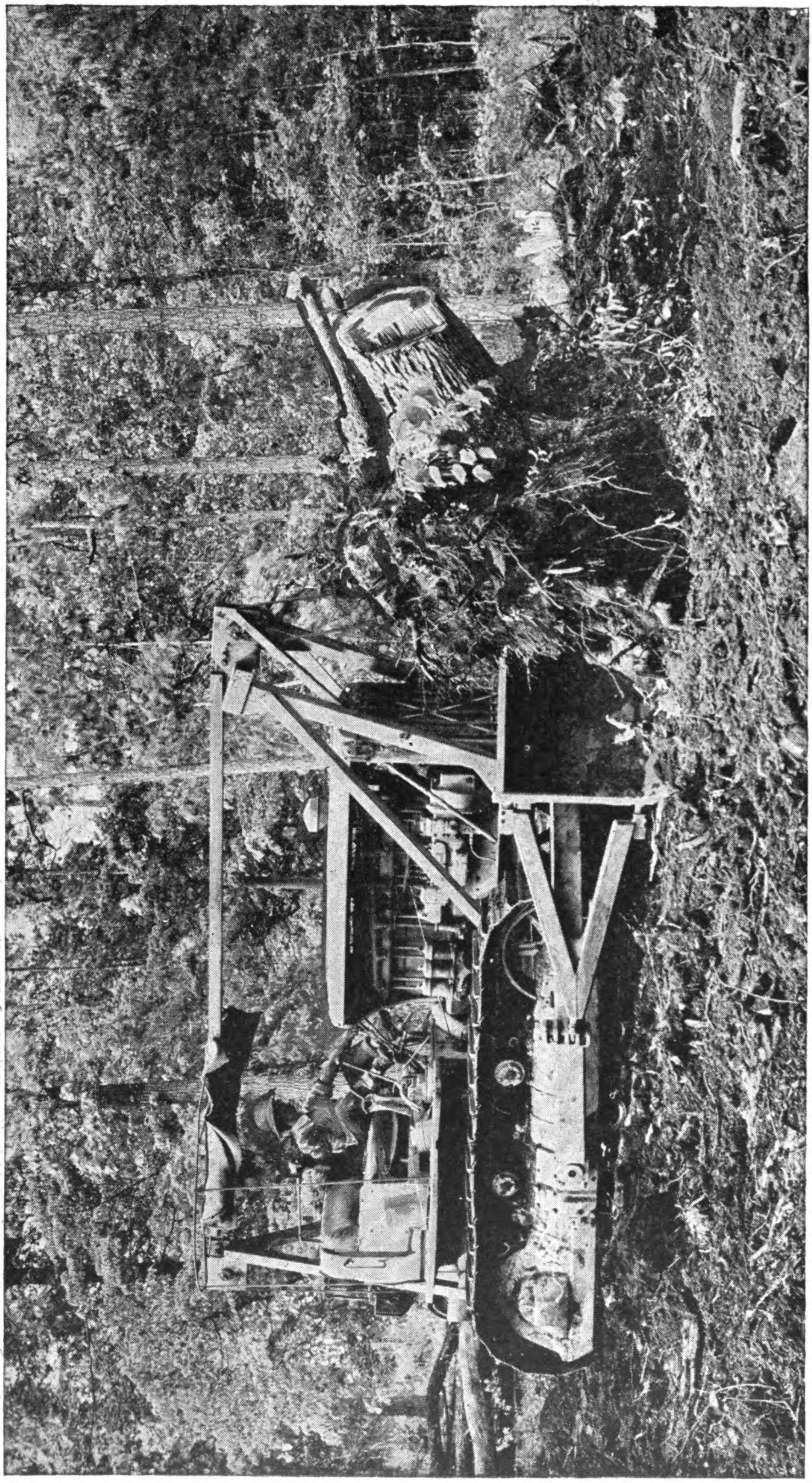


Figure 45. Grubbing stump with bulldozer.

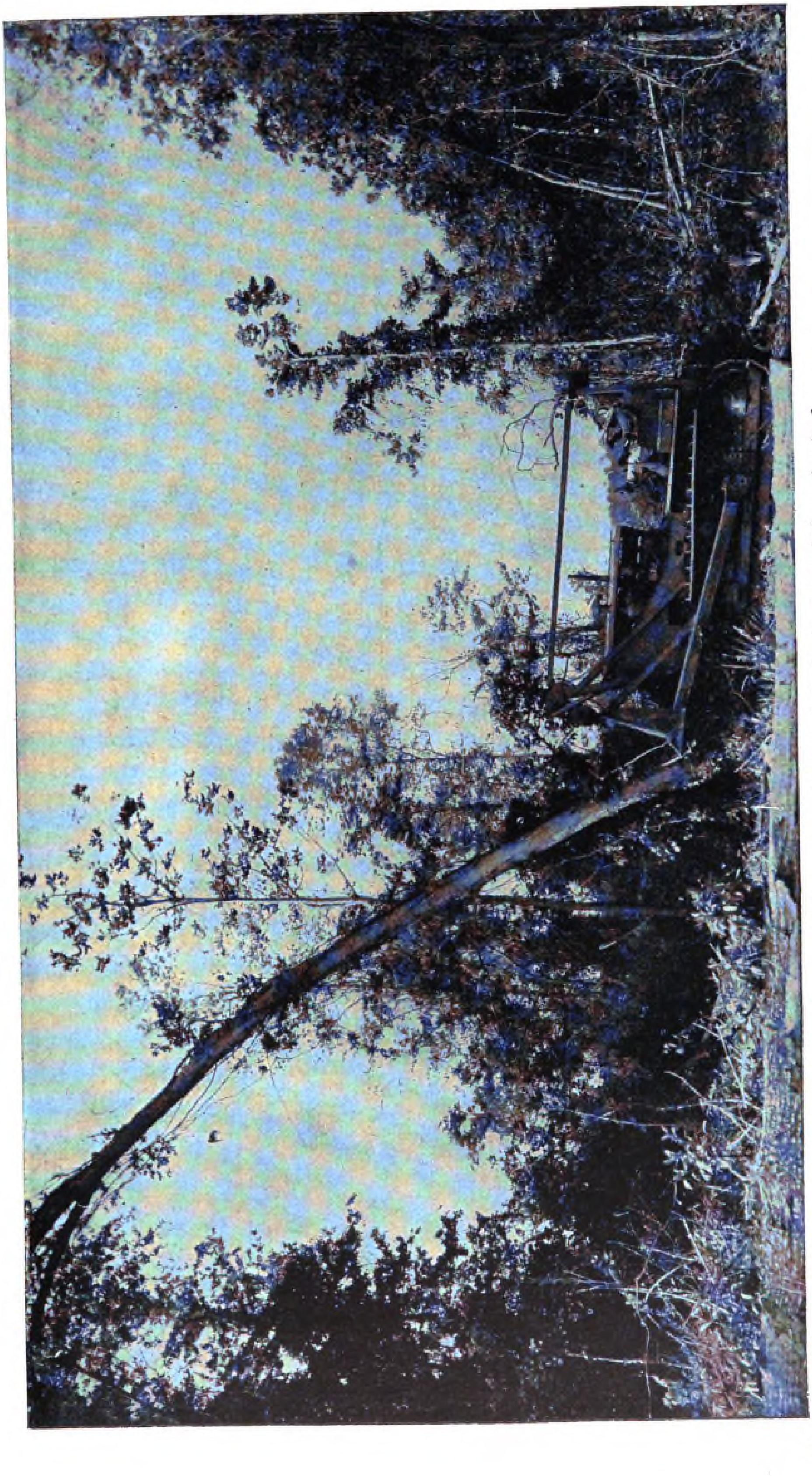


Figure 46. Tree removal by angledozer, blade straight and raised.

Figure 47. Removing cleared material from site.

design requirements for a base course. These areas should be utilized as possible "borrow" sources if above grade.

117. DRAINAGE. a. General. Properly designed and constructed drainage systems are vital to the functioning of an airdrome. Accumulations of surface water on landing strips and other airdrome installations are hazardous to aircraft operation (fig. 84). Wetting of subgrades by penetration of surface water or by flow or capillarity of ground water will reduce their load-supporting capacity and add to the danger of frost action. Drainage installations can be divided into two phases:

(1) Work necessary at the site to eliminate water which would interfere with construction operations. This work includes excavating diversion ditches to concentrate all surface water in natural channels, and building outfall ditches to drain low or boggy spots. Such work is an initial operation and may proceed concurrently with clearing and grubbing.

(2) Installation of all drainage facilities necessary for air operations at the airdrome.

b. Purpose. The drainage system must be designed to:

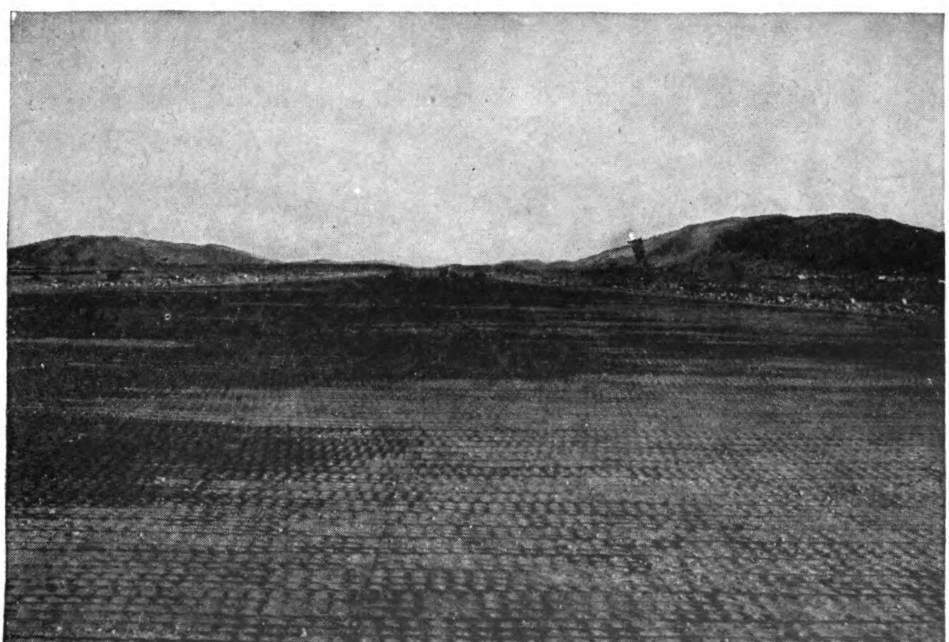
(1) Remove all surface water quickly from operating areas such as landing strips, taxiways, and hard standings.

(2) Intercept and divert surface water originating on land adjacent to airdrome operating areas.

(3) Remove or intercept detrimental ground water.

① *Start of operations. Boulder clearing from natural gravel foundation. Leveling course of granular material required to provide uniform bearing for steel landing mat.*

Figure 48. A landing strip from start to finish.



② *The finished landing strip.*

c. Removing surface water. Surface water from rain or melting snow is removed from landing strips by providing adequate transverse slope or crown. The minimum permissible transverse slope for drainage is 1 percent and the maximum is 2 percent (fig. 16). Transverse drainage is collected into side channels (fig. 49) and discharged into the nearest natural drainage channel. Surface water originating on land sloping toward the runway must be intercepted and diverted. Open intercepting ditches above cut slopes are desirable to minimize erosion and consequent filling of side channels with debris. Placement of sod (par. 203) will assist in preventing gulleys and wash-outs. Culverts must be provided under runways and taxiways at each natural drainage channel. Where standard construction materials are not available expedients may be devised (fig. 50).

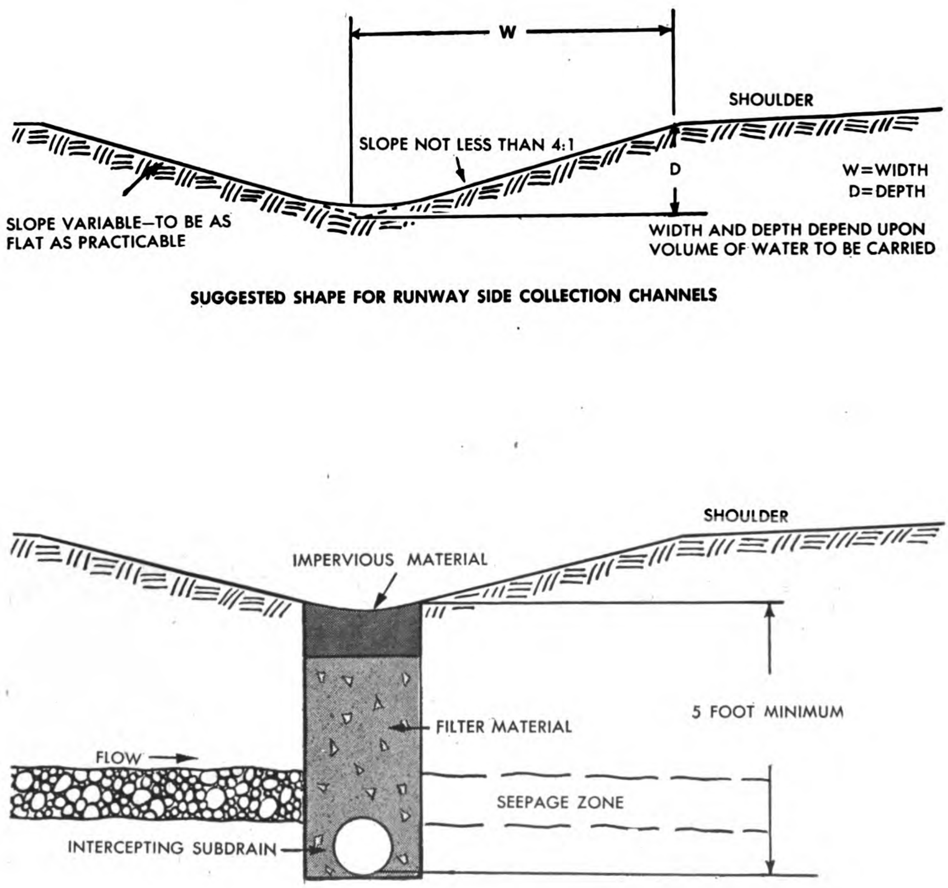


Figure 49. Suggested shape of side collection channels and position of covered intercepting drain.

Figure 50. An expedient culvert made of oil drums.

d. Removing spring and seepage water. All springs and ground seepages in the runway area must be drained. Sometimes subsurface seepage or flow toward the runway can be intercepted by the open side ditch or by a covered drain under the side ditch (fig. 49). Drains may be pipe (fig. 52) or stone, French or blind.

118. EFFECT OF DRAINAGE ON GENERAL DESIGN. The position of grade lines generally will be established by three factors:

a. Height of ground-water table (par. 122).

b. Shape and size of structures required in natural drainage channels crossing the landing strip (par. 120e).

c. Grading plan (par. 122).

119. TYPES AND FUNCTIONS OF DRAINS. **a**. Open channels are used to intercept or control the flow of surface water or to lower the ground-water table. Where landing strips are on ridges water may be discharged laterally. Parallel drainage is required on strips located on level ground and on ground sloping transverse to the landing strip or longitudinally with it. An open ditch located a reasonable distance from the strip creates no greater hazard than adjacent trees or other obstructions. Where there are no natural obstructions no artificial obstruction should be created which could cause damage to a plane landing in an abnormal manner. These conditions are illustrated in figure 51.

b. Covered drains (fig. 52) are used to collect and dispose of water in the base or of subsurface seepage and flow from springs or other sources.

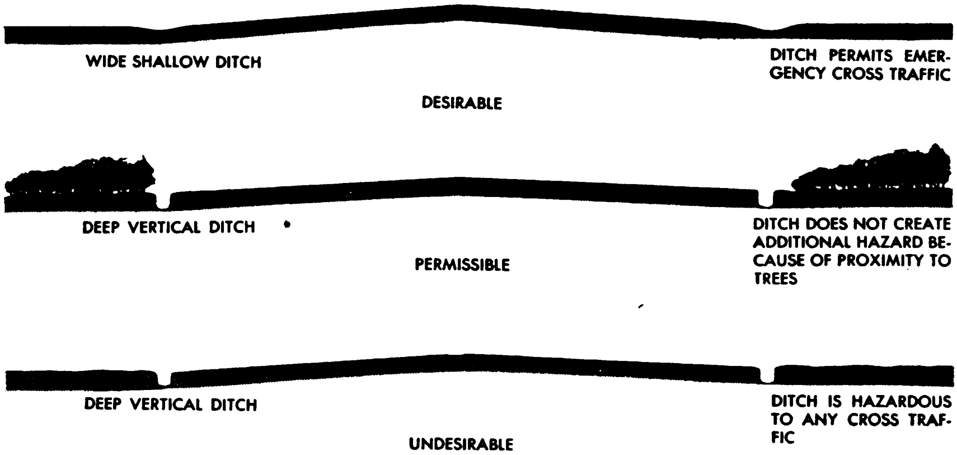


Figure 51. Schematic sketch of proper and improper ditch installation.

120. LAY-OUT AND DESIGN OF DRAINS. a. Basic data. The basic data to be considered are—

(1) Topographic map, showing natural drainage channels and relief of the site and contiguous areas which may contribute surface run-off.

(2) Rainfall data, particularly rainstorm intensity-duration data.

(3) Soil profile, showing elevation of the ground-water table and horizontal and vertical occurrence and extent of all soil types and their drainage characteristics (par. 79).

(4) Temperature and frost data, particularly maximum depth of frost penetration.

(5) Other factors such as snow, sleet, and ice, which may require special consideration in drainage plans and construction.

b. General lay-out. There is no standard lay-out for airdrome surface drainage. Each site presents an individual problem. Trial layouts are made on countour-map or aerial-mosiac overlays on which first are traced the natural drainage pattern—ridges and valley lines—of the area and the runway and taxiway lay-out. After an acceptable drainage scheme has been evolved it is checked for hydraulic adequacy by a series of trial computations. These cover estimates of the quantity of surface run-off to be carried by each part of the system and of the hydraulic capacity of each part.

c. Surface drainage. (1) Side collecting channels usually form the means for collecting surface run-off from runway areas and ordinarily consist of wide, shallow V-ditches (fig. 49) at or beyond the shoulder lines. Surface water is thus carried transversely across the shoulders to the side channels.

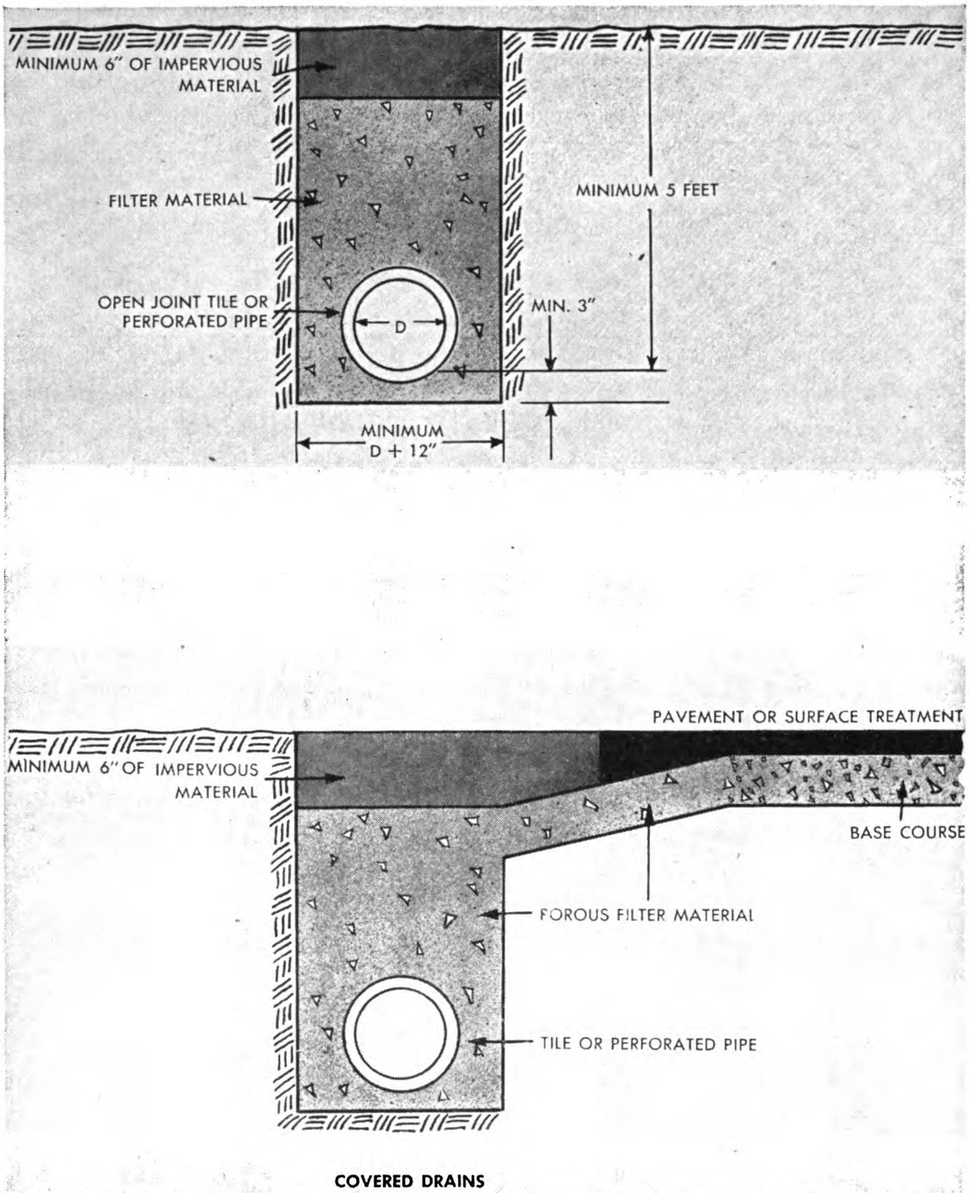


Figure 52. Typical sections of covered drains.

(2) Underground storm drains may be installed later as a part of the improvement program and will consist of a system of tile, concrete, or metal pipe, with necessary catchbasins usually located along the line of the side channels and in low interior areas of the field for removal of surface run-off. Pipes are laid with closed joints.

(3) Maximum permissible gradient of open ditches is largely determined by the type of soil and selection of grade may be guided by the following data:

MAXIMUM MEAN VELOCITIES PERMISSIBLE IN UNLINED DITCHES

Material	Mean velocity (Feet per second)
Uniformly graded sand and cohesionless silts	0.75–1.50
Well graded sand	1.50–2.50
Silty sand	2.50–3.00
Clays	3.00–5.00
Coarse gravel and cobbles	5.00–8.00

(4) To prevent accumulation of silt in pipes the gradient should be sufficient to give the water a velocity of at least 2½ feet per second. When sufficient grade is not available provision may be made at inlets for collection of silt by constructing the bottom of catchbasins below bottom of pipe invert.

(5) Catch basins required to admit surface run-off to underground storm drains may be constructed of wood, concrete, or masonry and should be provided with a cover designed to admit the design discharge and strong enough to support the maximum anticipated wheel load. Covers have been used made of 2- by 8-inch timber placed on edge at 4-inch centers and spanning the short dimension (not over 2 feet) of the basin.

(6) At every opportunity drainage water should be diverted or discharged from collecting channels into natural drains and away from the site, to reduce seepage from ditches into the subgrade.

(7) The soil profile may disclose existence of subsurface strata of porous gravel through which surface drainage water may be discharged. In such cases a porous, backfilled trench is constructed under the side channel to admit surface drainage to the subsurface strata.

d. Quantity of surface run-off. (1) Surface run-off may be estimated by the formula—

$$Q=CiA$$

in which—

Q=Rate of run-off from area A, in cubic feet per second.

A=Drainage area in acres.

C=Surface run-off factor from table X.

i=Rainfall intensity in inches per hour, which may occur during the time of concentration.

(2) Where relatively complete meteorological data are available the following general steps should be followed in determining values of i in the above formula.

(*a*) Select a design storm with an average frequency of occurrence from 2 to 10 years.

(*b*) Estimate time of concentration for various critical points of the drainage system.

(*c*) Select a value of i from the adopted design rainfall information for the estimated time of concentration.

(3) In the absence of compiled data, reasonable assumptions must be made. As a guide for comparison values of i for similar frequency storms in the United States with a duration of 1 hour vary from 1 to 3 inches. Intensities for storms of 30-minute duration vary from 1.5 to 4.5 inches per hour, and storms of shorter duration have correspondingly higher intensities.

e. Capacity of channels, culverts, and pipes. (1) Discharge capacity of all drains must be equal to or greater than estimated run-off to be carried. The following formula may be used for estimating water-carrying capacity of pipes and well-maintained open channels. Figure 53 is a chart for quick solution of this equation for pipes.

$$Q=A\frac{1.486}{n}r^{2/3}S^{1/2}$$

In which—

Q=Quantity of water drain will carry in cubic feet per second.

S=Hydraulic slope or gradient-fall in feet per foot of channel or pipe length.

r=Mean hydraulic radius of pipe or channel in feet.

$$=\frac{\text{Cross-sectional area of section}}{\text{wetted perimeter}}$$

A=Cross-sectional area of drain.

n=Coefficient of roughness; for concrete pipe=0.015; for bare-earth channels=0.025; for sodded channels=0.040.

(2) The chart shown in figure 53 is used in the following manner:

(*a*) The discharge of the drainage area is determined as in **d** above.

(*b*) The slope of the drainage channel is taken from survey notes.

(*c*) The quantity of discharge and the slope are marked on the respective lines on the chart.

(*d*) A straight line drawn through these two points is extended to an intersection with all four lines of the chart. The appropriate minimum size of circular pipe and the velocity of flow through the pipe are read at the intersections of the extended line. The dashed line drawn on figure 53 illustrates the following example:

Discharge (Q)=6 cubic feet per second.
Slope (S)=0.01 foot per foot.

Then—

Velocity (V)=4.6 feet per second.
Diameter of drain=15+ inches.

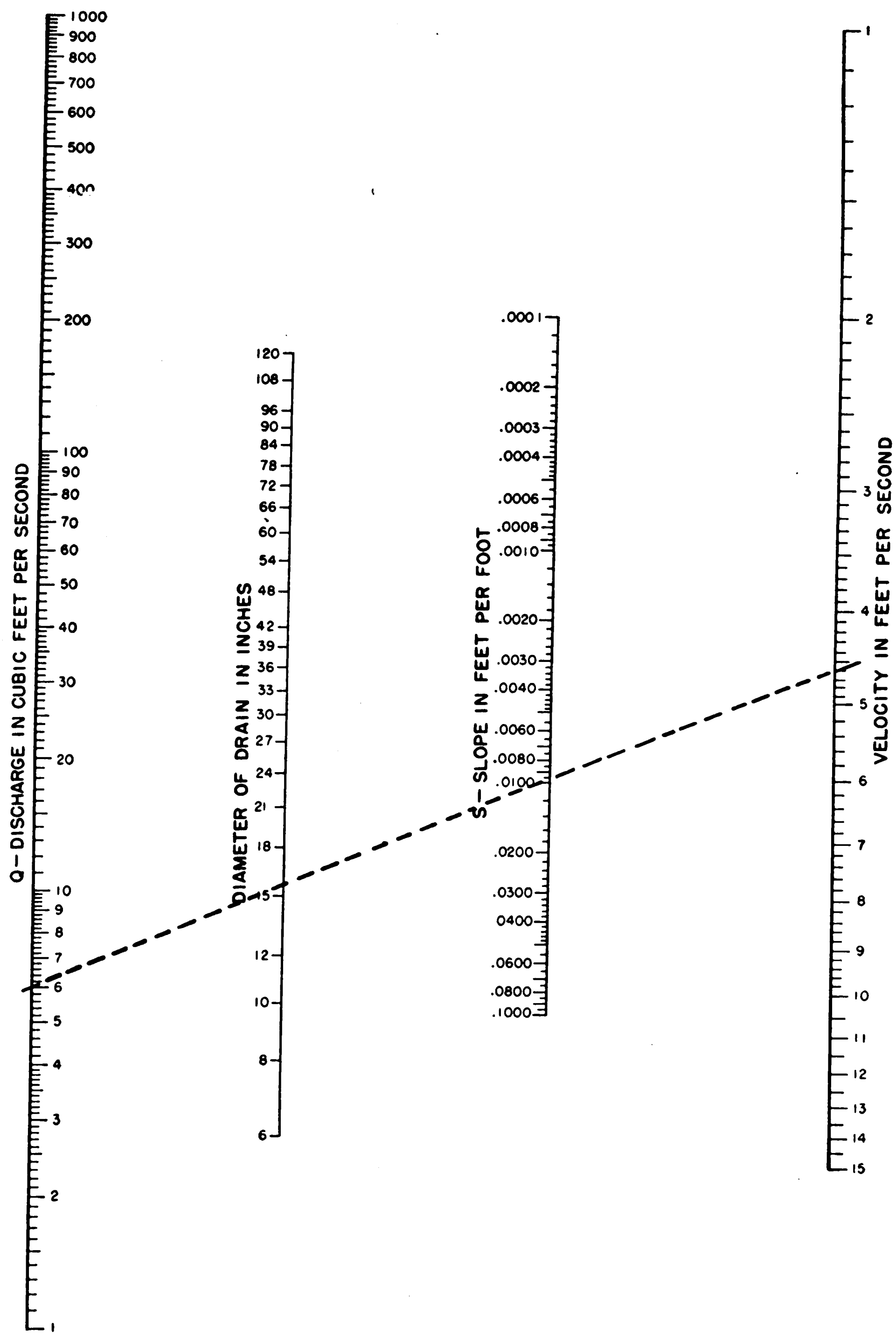


Figure 53. Graphical solution of $Q = A \frac{1.486}{n} r^{2/3} S^{1/2}$ *for circular pipes (based on Manning's formula for* $n = 0.015$*).*

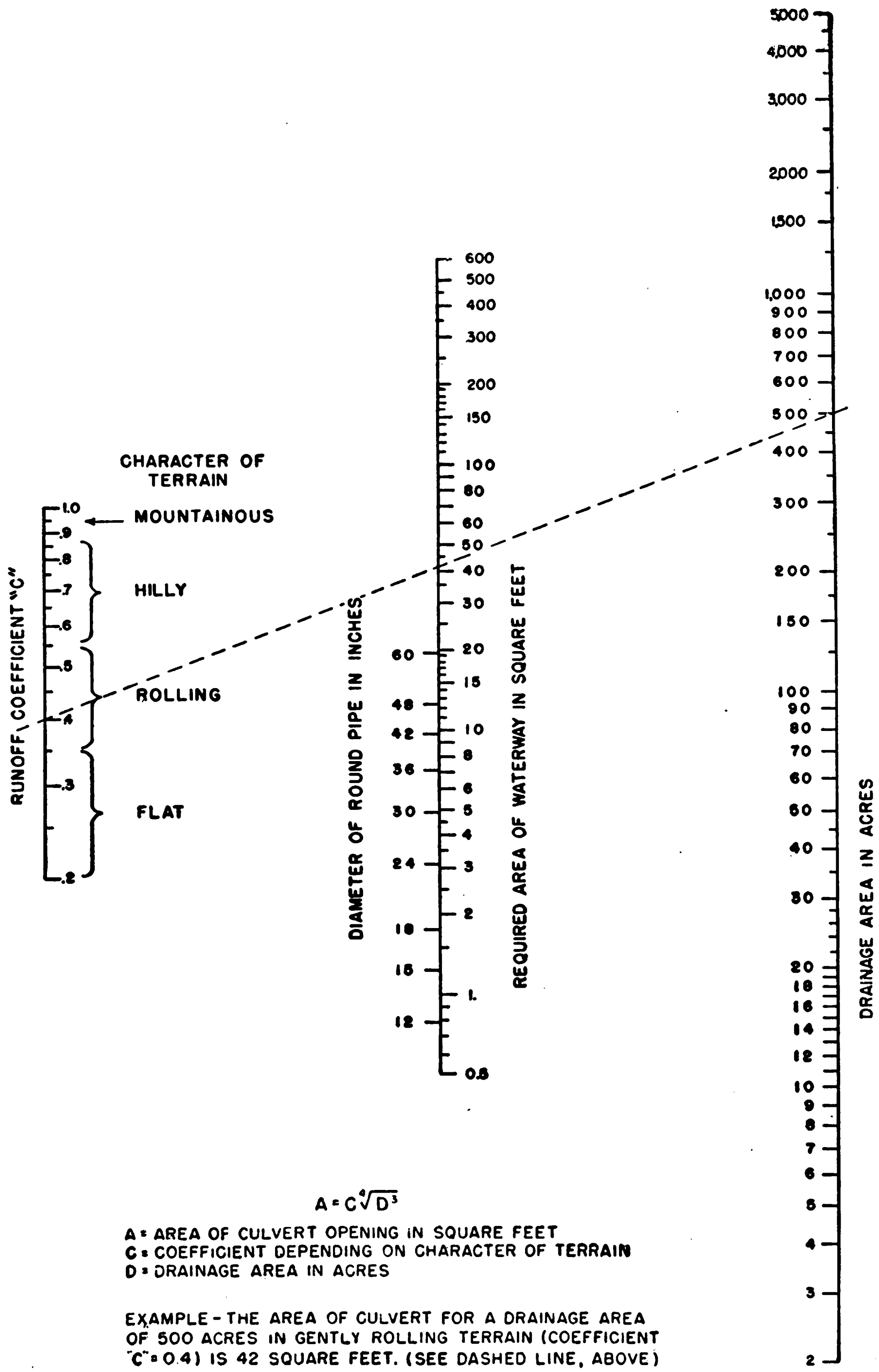


Figure 54. Culverts—nomograph for solution of formula: $A = C\sqrt[4]{D^3}$

Table X. Surface run-off factors.

Type of surface	Values of C
Impervious surfaces—pavements and roofs..................	0.70 to 0.95
Unpaved surfaces of compacted earth, sand, or gravel..........	0.10 to 0.30
Sodded areas—lawns and meadows.........................	0.15 to 0.25
Wooded areas (depending on surface slope and soil cover).....	0.01 to 0.20

(3) A quick method of estimating required culvert capacity for passing drainage water in natural channels under roads, taxiways, and runways is given in figure 54. This chart is based on a rainfall intensity of about 4 inches per hour for 1 hour duration. For locations having different rates for 1 hour duration an adjustment may be made by dividing the area of culvert (obtained from fig. 54) by 4 and multiplying by the 1-hour-duration rate at the location considered. No adjustment is recommended for rainfall intensities less than 4 inches per hour, unless based on complete meteorological data. For important culverts this chart should be supplemented by field examination of the watershed and waterway for evidence of past floods and unusual stream characteristics.

f. Subdrainage under runways. (1) Site selection of field airdromes generally will avoid low, wet areas requiring a complete system of subdrainage. Where this is not possible subdrains may be required under part of the runway. Also, certain fine-grained soils in regions subject to frost may require subdrainage to prevent frost-action damage to runways. When used for this purpose subdrains must be placed below the depth of frost penetration. All such subdrainage systems should be designed and installed in accordance with good engineering practice, as given in chapter 21 of the Engineering Manual on design and construction prepared by the Engineering Division, Office, Chief of Engineers, or in standard engineering texts.

(2) SUBSURFACE DRAINS. Subsurface drains usually are constructed of pipe, although of necessity may be French drains constructed of stone or gravel. Perforated or open joint tile pipes used in such drains should be placed at least 5 feet below the surface except where used solely for base course drainage. From 6 to 8-inch tile is normally adequate for base-course subsurface drains. Trenches should be filled with suitable filter material, except the top 6 to 12 inches which should be filled with impervious material. When subsurface drains are used under or adjacent to the side of the runway, the filter material should join the base-course layer. Base course material outside the pavement or surface treatment should underlie an impervious layer. Collected drainage is discharged into outfalls to natural drainage channels as quickly as possible.

(3) FILTER MATERIAL FOR PIPE DRAINS. Many failures of drainage systems and pavements have been caused by movement of soil from the trench walls into the filter material used to cover the pipe and fill the trench. This has resulted in pavement collapse along the edges or in complete clogging of

the drain, emphasizing the importance of selecting filter material carefully. Filter material should be as pervious as possible and still have a gradation which will prevent movement of soil from the sides of the trench. The required gradation is governed by the gradation of the adjacent soil. Gradation of the filter material should meet the following requirements:

$$\frac{\text{15 percent size—filter}}{\text{85 percent size—uniform soil}} \quad \text{not greater than 4.}$$

$$\frac{\text{15 percent size—filter}}{\text{85 percent size—well-graded soil}} \quad \text{not greater than 5.}$$

$$\frac{\text{15 percent size—filter}}{\text{15 percent size—uniform soil}} \quad \text{greater than 5.}$$

$$\frac{\text{15 percent size—filter}}{\text{15 percent size—well-graded soil}} \quad \text{greater than 25.}$$

The percent size is grain size, corresponding to the percent finer by weight on the sieve-analysis curve (par. 5d, app. III and fig. 280). For drain pipes with large openings a layer of coarse material adjacent to the pipe is required to prevent movement of filter material into it. Where the subgrade soil is definitely cohesive a greater difference between backfill and natural material can be allowed. Since the most unstable soils are fine sands and coarse silts, special attention should be given to selection of filter materials wherever these types of soils are encountered.

g. Combination drains. Under special conditions, such as expediency of construction, anticipated short life of airfield, or unusual soil conditions, the use of combination drains may be permissible. The combination drain usually encountered consists of a base-course drain (fig. 52) modified to permit entrance of surface run-off by substituting coarse-graded crushed rock or washed gravel mixed with bituminous material for the impervious top layer. To permit rapid removal of surface water a more open gradation of filter material is suggested. There are marked disadvantages to this type of drain which under normal conditions will result in decreased efficiency of the drain and in much higher maintenance requirements for runway surface adjacent to the drain and for cleaning catchbasins and drain pipe.

h. Depth of cover on drains and culverts to resist external loads. Table XI shows the minimum depth of cover above drain and culvert pipes necessary to resist pressures transmitted downward from wheel loads. Pipes of greater strength, or concrete encasement, will allow a decrease in the required cover thickness.

121. CONSTRUCTION OF DRAINAGE FACILITIES. a. General. Principal items involved in the construction of a drainage system are—

(1) Open ditches with sloping sides.

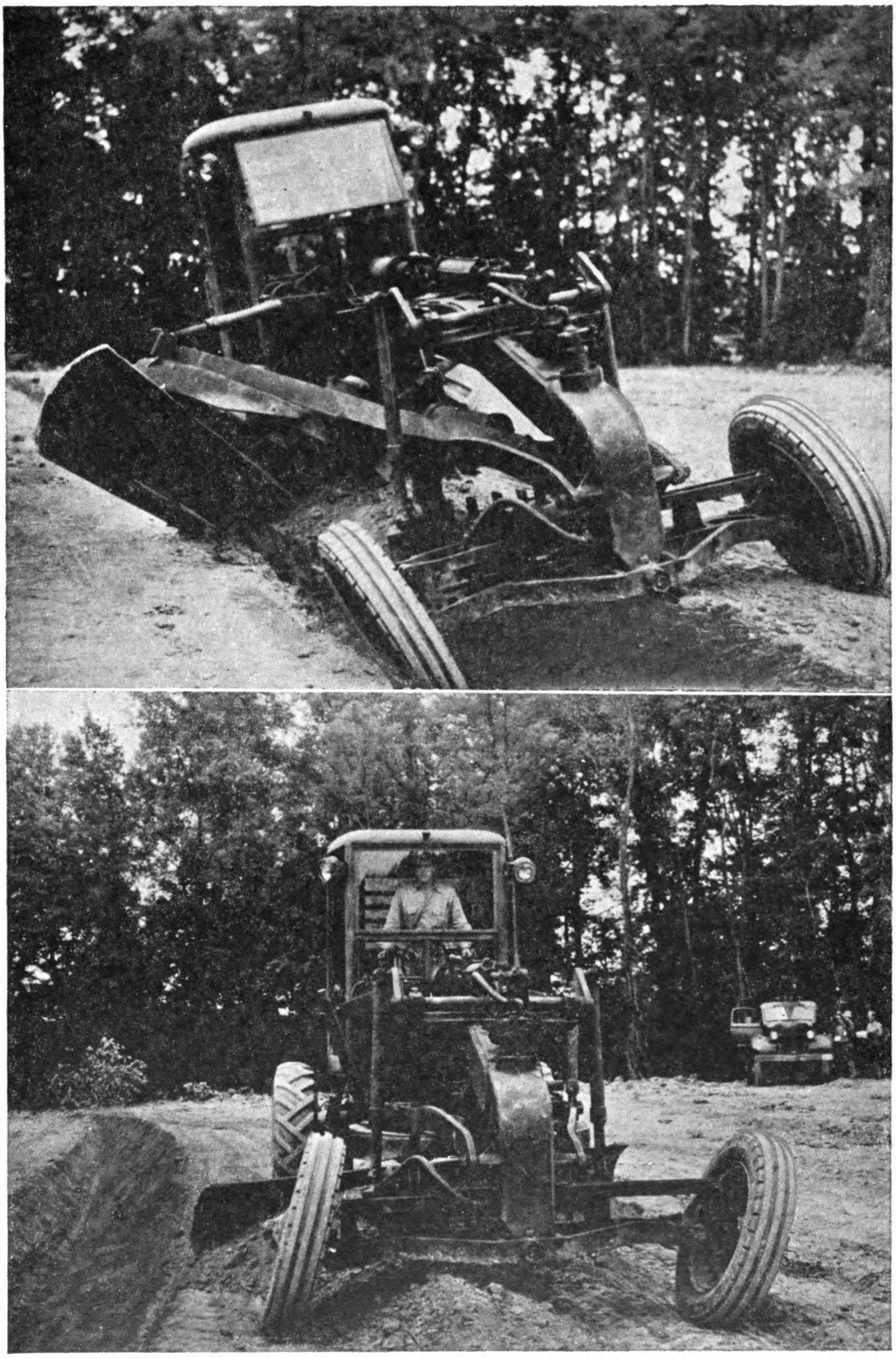


Figure 55. Motor grader cutting open drainage ditch.

(2) Narrow trenches or ditches with vertical sides backfilled with select filter material, covering tile or perforated pipe in the bottom.

(3) Drainage structures such as culverts, catchbasins, and junction boxes.

Table XI. Minimum depth of cover above top of drain and culvert pipe to resist bomber wheel loads.

Size of pipe	Minimum depth of cover in feet	
	Clay and concrete pipe	Corrugated metal pipe
6-inch diameter	2.5	1.0
Up to 12-inch diameter	3.0	1.5
18-inch to 36-inch diameter	4.5	3.5

b. Methods. (1) Open ditches (fig. 49) with sloping sides may be excavated with grader (fig. 55), dozer, scraper, power shovel, or dragline, depending upon the size of the ditch and the prevailing working conditions. (2) Narrow trenches or ditches with vertical sides normally are excavated with the ditcher (fig. 56). Best progress is made by this machine if it travels downgrade while digging. To insure proper flow of drainage water the ditcher must dig down to, but not below, the grade set for the bottom of the trench. Digging closely to grade eliminates both slow hand-trimming of the portions of the trench bottom which are above grade and backfilling and

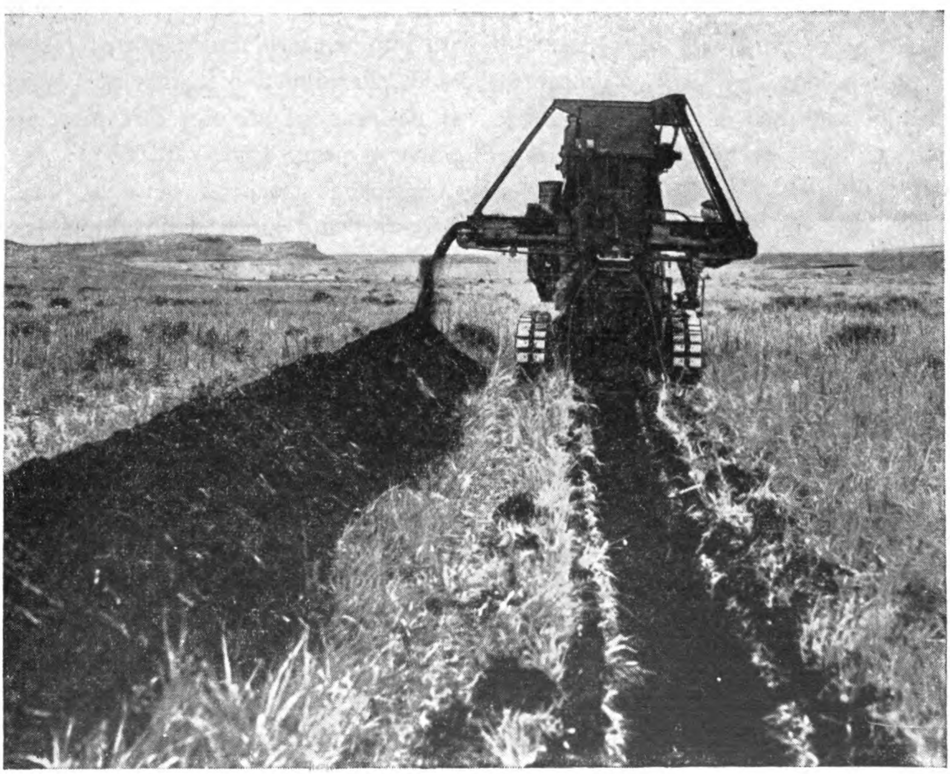


Figure 56. Ditcher digging trench for tile drain.

tamping the portions below grade. Where water will accumulate in the trench during construction the trench must be excavated uphill against the grade to avoid working in the water.

(3) When sections of rock or cemented soil or gravel, called hardpan, are encountered it is necessary first to loosen this material along the ditch line by rooter or by blasting (FM 5–25).

(4) Bracing or shoring may be necessary to keep the trench open and the bottom clean until tile or pipe is laid and the backfill is placed.

(5) Material excavated from the trench may be loaded into trucks while trenching or spilled into a continuous pile along the trench. Subsequently it is spread by grader or dozer. It may also be removed by a scraper and placed in a fill or otherwise conveniently wasted.

(6) Backfill must be placed and compacted in layers to minimize settlement wherever the trench is at the edge of or under a runway, taxiway, hard standing, or road. The compressed-air tamper or hand-tamping may be used. Top portions of backfill in trenches may be compacted by running a loaded truck back and forth with wheels in the trench. Where the trench is backfilled with specially selected filter material precautions must be taken to prevent soil or other fine material from getting mixed with the backfill. Gravel or crushed-rock backfill must be clean, screened material meeting the size requirements given in paragraph 120f. Tile in trenches is placed with open joints to admit water. The joint spacing should be one-half the dimension of the smallest size stone in the backfill material surrounding the pipe. The top of each joint should be covered with metal strips or with bitumen-saturated paper or fabric to prevent fine soil from getting into the tile. Perforated pipe may be placed with perforations either up or down. If perforations are up, care must be taken to select backfill material that will prevent silting (par. 120f (3)).

(7) To provide proper hydraulic flow, drainage structures must be built closely to required grade. Culverts, catch basins, and junction boxes may be built of logs, sawed timber, rock, brick, or concrete, depending upon material and construction time available and probable length of service required. Foundations for these structures must be firm. Catch basins and junction boxes should have removable covers to give access for cleaning. Covers must be strong enough to carry loaded truck or aircraft wheels if such loads may pass over them.

(8) Springs and seepage encountered in runway excavation may require exploratory excavation in the seepage area and construction of branch subdrains to the limit of such excavation; or, construction of an intercepting drain outside the runway limits.

(9) The outside bottom surface of culverts of corrugated metal, clay pipe, or concrete pipe must be bedded on firm soil excavated true to grade, with a rounded surface against which the bottom of the tile or pipe will fit snugly for at least one-fourth its circumference. It is important to remove rock projections from the bottom of the trench and replace with tamped earth. Fill

under and around the sides of culverts should be well compacted. A 12-inch cover of fill should be placed above the top of culverts before machine compaction is used. Backfill should be placed in approximately 3-inch lifts on both sides of the culvert at the same time and throughout its entire length. This prevents unequal settlements or pressures which could distort or displace the culvert.

122. GRADING AND COMPACTING. a. General. The best progress in grading operations results from job organization that permits quick loading and unloading, minimizes idle equipment, and provides a capacity load each trip. Length of haul also is an important factor. Each job must be analyzed to determine correct equipment assignments and necessary aids such as pushers, rooting, or blasting, to keep major units working efficiently. Circulating travel of hauling units eliminates backing to load or unload. Surface drainage should be provided at all stages of earthwork to avoid accumulation of water which will slow or bog down equipment. A thorough knowledge of the characteristics and methods of handling of the soils encountered will accelerate the work.

b. Establishing position of grade line. Criteria for rates of grade, transverse slopes, changes in grade, and sight distances are given in chapter 7. Besides these the height of the ground-water table, the size and shape of cross-drainage structures, and the typical cross-section design also impose limitations that influence the position of the grade line. Within these limitations the grade line is established, to minimize the amount of earthwork and to take advantage of the best soils. Steps to be taken in positioning the grade line are:

(1) Surveying the site (par. 79).

(2) Determining culvert or structure sizes for channels crossing the site (par. 120e).

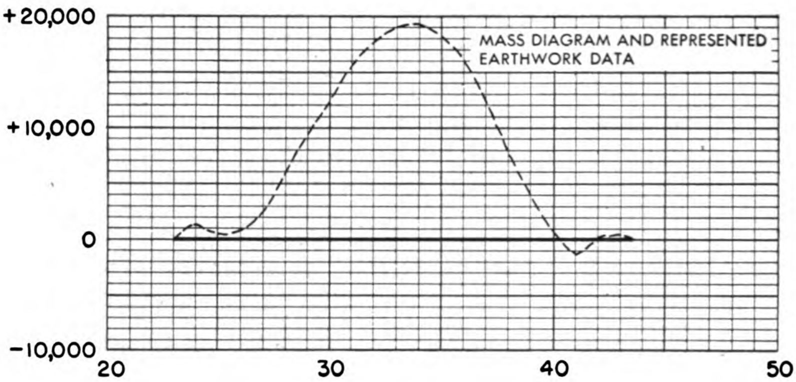
(3) Plotting profiles and cross sections. This should proceed concurrently with surveys. Ground-water elevation, soil data, and restrictions imposed by drainage structures should be noted on profiles (TM 5–230) to indicate control points used in laying the grade.

(4) Upon completion of the foregoing, a trial grade is laid and volumes are figured by the average-end-area method (fig. 128). A well-designed grade line will comply with the following:

(*a*) Minimum distance between ground-water table and the shoulder point on the landing strip at the same survey station should be 4 feet. This distance may be reduced somewhat if the subgrade soil is a granular material whose stability is not affected by moisture.

(*b*) The grade line at the shoulder point should not encroach on the minimum clearance required above drainage structures (table XI).

(*c*) Water-ponding on surface is minimized by using light (0.4 percent) longitudinal grades in place of flat grades (0.0 percent).



Station	Grade %	Grade Elev.	Interval Cut or Fill Ft.	Excav. Cu. Yd.	Excav. X Factor (0.8) Cu. Yd.	Embank, Cu. Yd.	Algebraic Sum	Ordinate
23	+0.4%	1,250.0	C 0.0	1,520	1,215		+1,215	0
24		1,250.4	F 2.0	55	44	980	− 936	+ 1,215
25		1,250.8	F 1.0	540	432	250	+ 182	+ 279
26		1,251.2	C 1.0	2,765	2,212		+2,212	+ 461
27		1,251.6	C 2.0	4,000	3,200		+3,200	+ 2,673
28		1,252.0	C 2.0	4,000	3,200		+3,200	+ 5,873
29		1,252.4	C 2.0	4,000	3,200		+3,200	+ 9,073
30		1,252.8	C 2.0	4,000	3,200		+3,200	+12,273
31		1,253.2	C 1.0	2,765	2,212		+2,212	+15,473
32		1,253.6	C 0.0	1,520	1,215		+1,215	+17,685
33		1,254.0	F 1.0	540	432	250	+ 182	+18,900
34		1,254.4	F 2.0	55	44	980	− 936	+19,082
35		1,254.8	F 3.0			2,095	−2,095	+18,146
36		1,255.2	F 4.0			3,240	−3,240	+16,051
37		1,255.6	F 5.0			4,420	−4,420	+12,811
38		1,256.0	F 5.0			4,420	−4,420	+ 8,391
39		1,256.4	F 4.0			3,240	−3,240	+ 3,971
40		1,256.8	F 3.0			2,095	−2,095	+ 731
41		1,257.2	C 0.0	1,520	1,215		+1,215	− 1,364
42		1,257.6	F 1.0	540	432	250	+ 182	− 149
Totals				32,820	22,253	22,220		+ 33

Figure 57. Earthwork mass-diagram.

(*d*) Excavations should be limited, if possible, to areas which develop material suitable for stable subgrade construction.

(*e*) Allowance must be made for shrinkage or expansion of materials moved from cuts to fills. Excavated materials other than rock shrink when compacted in fills or embankments. Average soils require 110 to 130 cubic yards of excavation to construct 100 cubic yards of compacted embankment. One hundred cubic yards of solid rock make 125 to 140 cubic yards of embankment. These figures are approximate and should be used as a guide only when definite figures based on tests described in paragraph 13, appendix III, are not available.

(*f*) The grade line should be laid to insure doing a minimum volume of earthwork with the least possible haul. This condition results when the volume of excavation is just sufficient to construct embankments without any excess. In arriving at comparative figures imported materials required to stabilize the subgrade must be considered as part of the excavation. A simple mass diagram will assist in planning this operation.

(*g*) A mass diagram is a graph prepared by plotting the algebraic sum of the embankment and the excavation, corrected to embankment value, as the ordinate, against the linear distance as the abscissa. Algebraic sums are obtained by using excavation quantities as positive and embankment quantities as negative. See figure 57 for an illustration. When used in conjunction with profile plotting of ground line and grade (fig. 58) the diagram is the basis of a plan for moving excavation to the proper embankment area with minimum haul. If the trial grade develops an excess of excavation or embankment, the diagram not only indicates such excess but also shows the areas in which repositioning of the grade line is required. If only a nominal excess of cut or fill results, the trial grade line should be adopted as final.

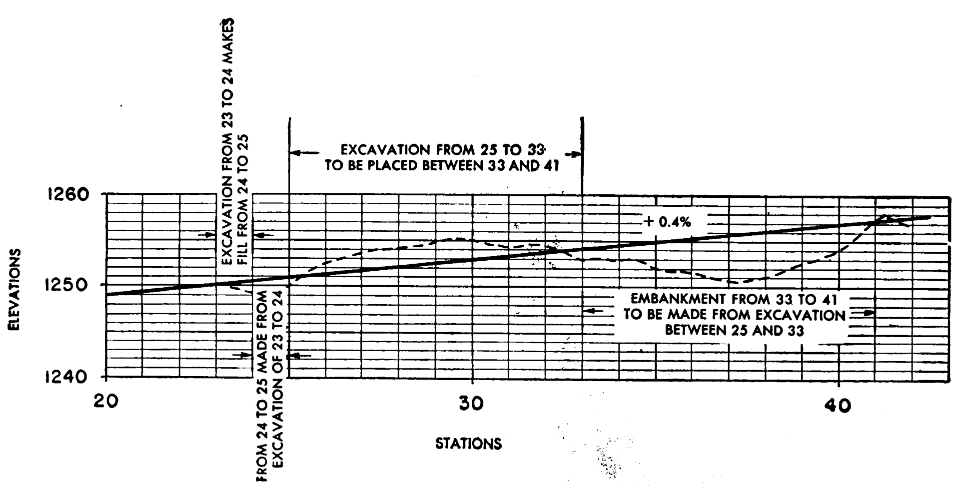


Figure 58. Ground profile with grade line and earthwork plan based on mass-diagram. (See mass-diagram, fig. 57 for placement of materials.)

c. Excavation methods. General excavation and embankment is accomplished by scraper (fig. 59), dozer, or shovel and truck. Equipment is assigned where it will be most effective.

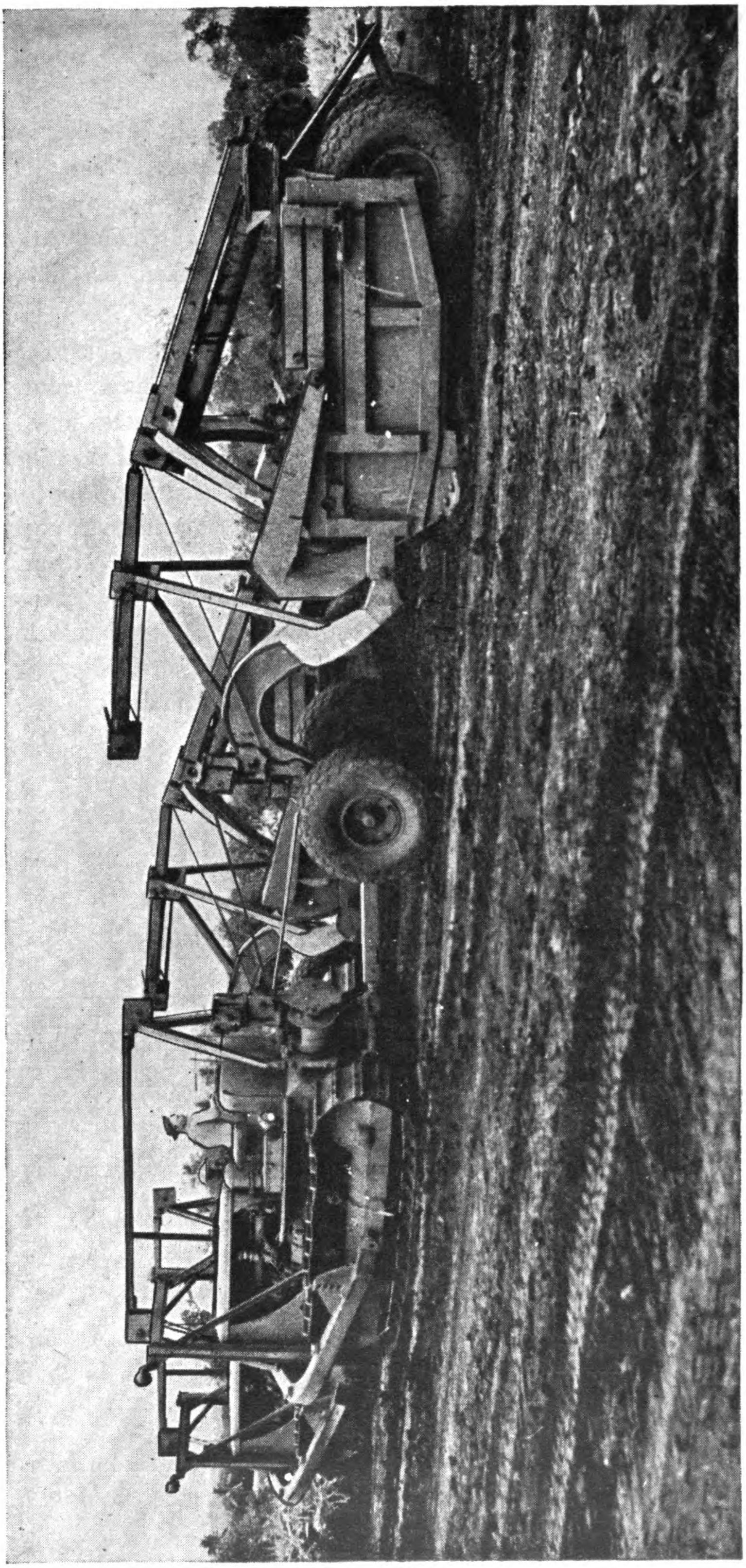
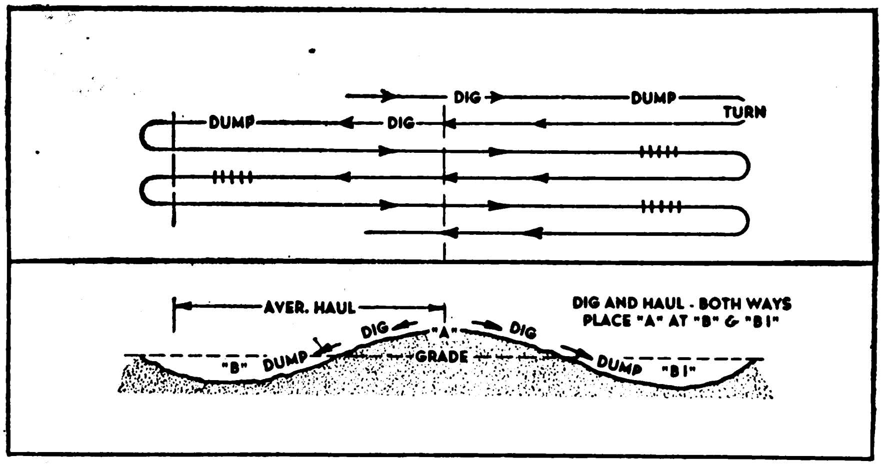


Figure 59. Towed scrapers grading runway.

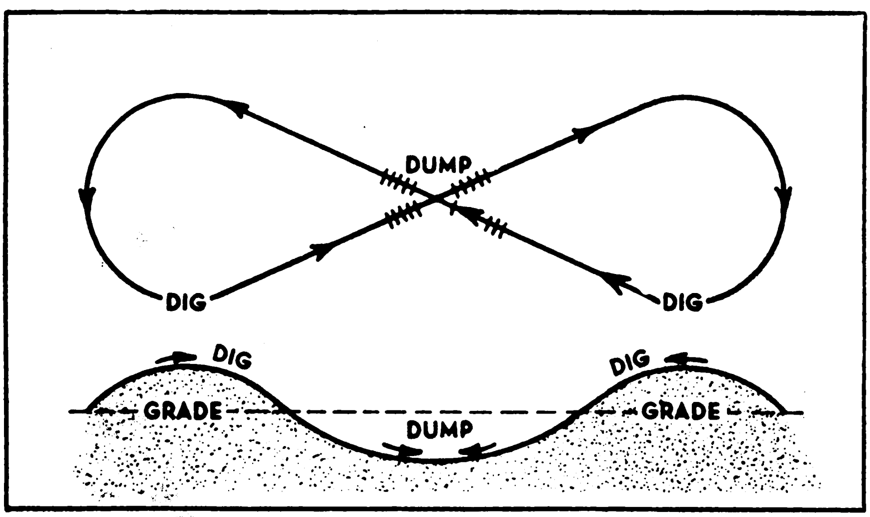
Figure 60. Motorized scraper loading, helped by a pusher tractor.

(1) Scrapers are used for earthwork extending over considerable area involving cut and fill in successive layers. The motorized scraper (fig. 60) is better adapted to long hauls than the tractor-drawn scraper because of higher traveling speeds, but requires a pusher tractor in loading. Maximum production is obtained if scrapers can haul a load going and coming, thus eliminating time lost in extra turns (fig. 61). In hard ground a pusher tractor, or loosening by rooter, is necessary for quick loading and high output. The rooter always is operated with teeth symmetrically spaced. If one tooth of a five-tooth rooter is broken or removed, the corresponding tooth on the other side also is removed. Rooter points always must be raised while turning.
(2) The dozer is used where earth is to be drifted short distances and where turn-around space is limited. It is particularly adapted to stripping, end-

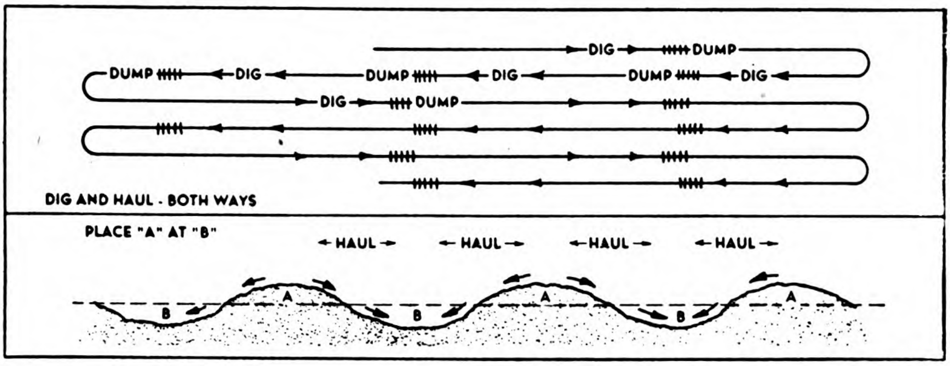


① *Lay-out with fills on both sides of a cut.*

Figure 61. Plan of scraper operations to increase production by eliminating turns.



② *Lay-out with fill between two cuts.*



③ *Lay-out with alternate cuts and fills.*

Figure 61. Continued.

casting in fills, side-casting in initial stages of side-hill cuts (figs. 62 and 63), and in initial stages of through cuts. Best progress is made if material can be drifted downhill. The dozer also may be used in excavating basements or underground storage facilities and for constructing earth traverses. Disposal of earth from relatively shallow excavations of sufficient horizontal area to allow some maneuvering of the tractor may be expedited by using a strong, skid-mounted timber incline up which the dozer pushes the excavated earth. The upper end of the incline should be high enough for truck bodies to receive earth pushed over by the dozer.

(3) Power shovels are used in situations where large yardage can be reached with infrequent shovel moves. Generally, disposal is by truck but casting over the side may be used in side-cut work. Stripping and clearing for shovel

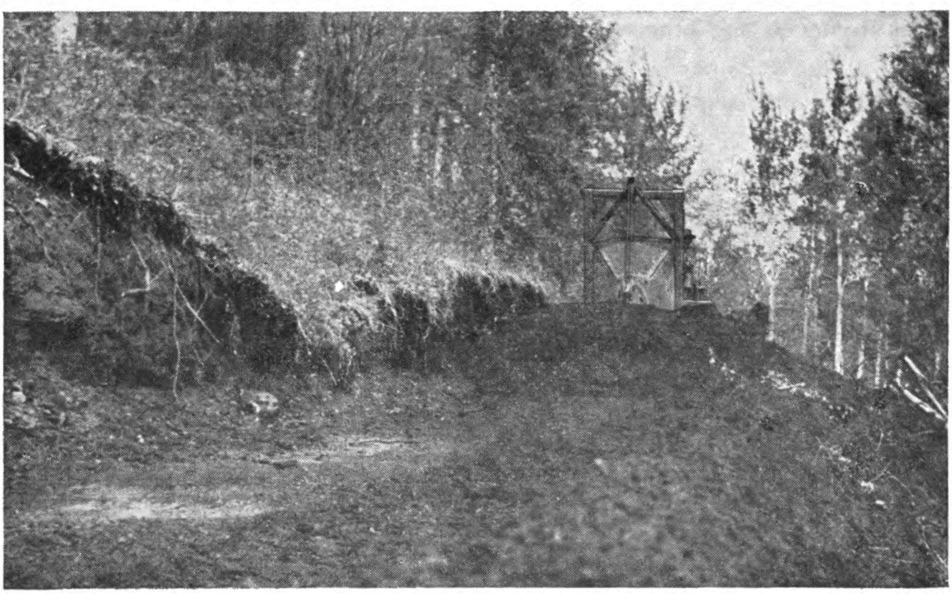


Figure 62. Angledozer opening a sidehill cut.

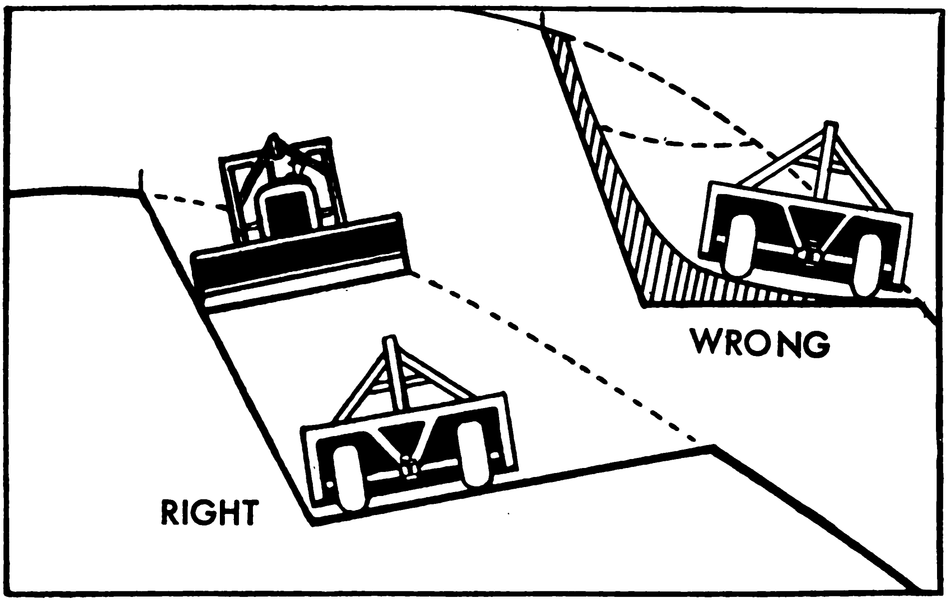


Figure 63. Sidehill cut opened with angledozer and finished with scraper. Cut is kept low next to slope and high on outside.

excavation may be done with the dozer. The clamshell and dragline are used for underwater excavation and for dry excavation below working grade.

(4) Holes for poles may be dug by the earth auger. Excavations for narrow footings, trenches, and latrines may be dug with the ditcher.

d. Constructing fills (embankment). (1) Requirements prior to fill construction include placement of all culverts, draining all ground seepage and springs in the area to be covered, and preparing the foundation. Stump holes, trenches, and other excavations must be filled and compacted in layers to the original ground surface before placing any fill. Embankment foundations must be reasonably free from organic material such as leaves and brush, especially on sloping ground, to avoid seepage slip-planes which may result in slides. Stripping may be necessary. A few light cuts with a rooter or plow along the contours of a hillside will improve the bond between foundation and embankment.

(2) In general, *all fills of plastic or cohesive soil must be built up in compacted layers not thicker than 9 inches.* Scrapers spread the soil in layers while unloading. A grader or dozer may assist in spreading and smoothing. *Each layer should be uniformly compacted at controlled moisture content.* The desired degree of compaction is at least 90 percent of maximum density, as determined by the modified AASHO test (par. 10, app. III). Moisture content during compaction of plastic soils should be approximately optimum content (par. 10, app. III). Generally, this is less than 20 percent of dry weight. At optimum moisture soil feels slightly damp and firm when squeezed in the hand. Periodic moisture and field density tests are required to control

compaction progress (par. 12, app. III). (See table V and par. 96 for additional data on soil compaction.)

(3) Earth fills are compacted with a sheepsfoot roller (fig. 64). Supplemental compaction may be obtained by distributing travel of construction equipment over the fill area. The sheepsfoot roller compacts a layer of loose soil from the bottom up. With each pass the roller penetrates less. The action is called "walking out" or "rolling out." The tamping effect of the sheepsfoot may be increased by loading the roller drums with water, oil, or sand. Continuation of rolling after the required compaction has been obtained is a waste of time and effort. The penetrating and cutting action of the roller feet leaves a mulch of 1 to 2 inches of loose material at the top of each layer compacted. This assists in bonding successive layers. At the final surface, rubber-tired or flat-wheel rollers must compact this loose material to a smooth dense surface.

(4) Rubber-tired and flat-wheel rollers may be used for compacting thin layers of soil, but are less effective than the sheepsfoot roller since they compact from the top down. This disadvantage is somewhat offset by the kneading action of the rubber-tired roller.

(5) Soil for embankments which does not contain sufficient moisture must be dampened. It may be moistened in the excavation area or a layer at a time on the fill. When water is added on the fill the sheepsfoot roller is passed over the layer just before sprinkling. This allows water to collect in pockets and to filter uniformly through the soil with minimum evaporation loss. Soil that is too wet, as after a rain, must be allowed to dry before compaction. Manipulation of the too-wet layer with plows, harrows, scarifier, or grader, will aid evaporation.

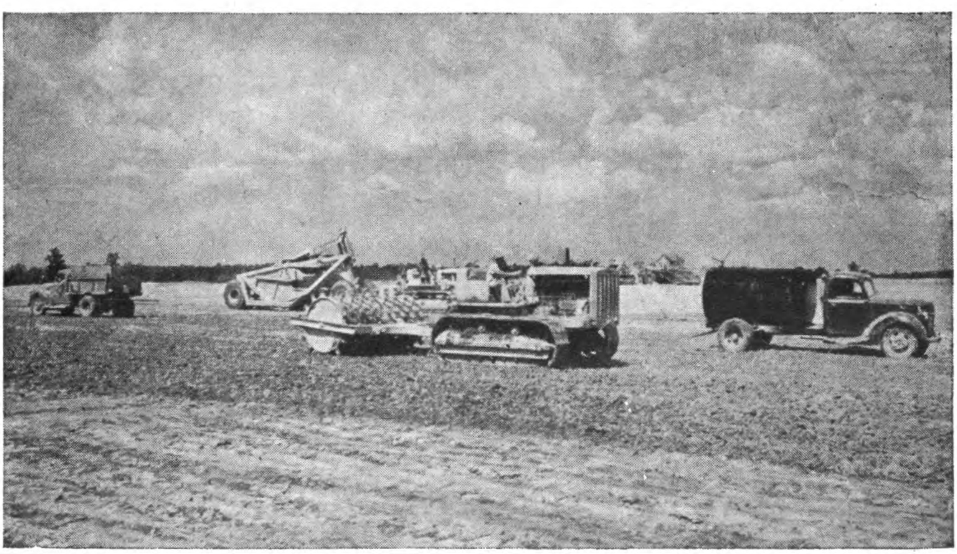


Figure 64. Sheepsfoot roller compacting runway subgrade at controlled moisture content.

(6) Fill material of clean sand or clean sandy gravel is compacted best when it is saturated. Because vibrating action usually is necessary for compaction, the track type tractor gives good results. Sometimes saturation alone will compact sand sufficiently for ordinary purposes. Saturation may be accomplished by ponding the surface of the fill, or by jetting if water is available under pressure. Jetting introduces water into the fill through perforated pipes pushed into the material.

Caution: Do not saturate plastic or cohesive soil.

(7) Poorest soil materials are put in the lower layers of fills when possible. Select material, determined from the soil survey, encountered in excavation should be placed on top of the fill to improve the subgrade. A depth of 9 inches is desirable. If excavation does not produce suitable select material, it may be borrowed from adjacent sources located by the soil survey.

(8) Rock ordinarily is placed in the bottom of fills. If an entire fill is built of rock, it is finished off a few inches below subgrade elevation to allow for a cushion layer of select excavation or select borrow. It is preferable to place rock fills in layers not thicker than the size of the largest rock fragments, but end-dumping for the full height of the fill may be necessary.

(9) Embankment around structures must be built up around all parts of the structure in equal compacted layers approximately 3 inches thick. Tamping with compressed air hammers or hand tools is necessary in areas inaccessible to regular compaction equipment.

CHAPTER 14

SUBGRADE PREPARATION AND STABILIZATION

123. FUNCTION OF SUBGRADE. The subgrade is the foundation which supports any load placed on the surface of a runway, taxiway, hard standing, or road. Its strength determines the thickness of pavement and base (par. 131).

124. EVALUATION OF SUBGRADES. Subgrade soils are evaluated in advance by the soil survey (par. 79). Confirmatory tests are desirable during construction to verify the survey and plan and, if necessary, to alter operations to get the best results. Laboratory tests of California bearing ratio (CBR) and density are desirable (pars. 10, 11, and 12, app. III). Practical tests include observation of the behavior of the subgrade under loaded trucks or tests of trial sections of subgrade covered with the proposed base (par. 131g).

125. PREPARATION OF SUBGRADE. After earthwork and fill compaction are completed the subgrade is brought to the intended lines and grades as established by grade stakes (par. 114).

a. Plastic soils. Except in areas of cut where the soil is clay, the entire area of subgrade is scarified to a depth of 6 to 9 inches and then moistened by sprinkling to approximately optimum moisture content. Next, it is compacted with sheepsfoot rollers, preferably to 95 percent of maximum density as determined by the modified AASHO test (pars. 10 and 12, app. III). Graders distribute the material to exact grade. Finally the subgrade is sprinkled lightly and rolled with rubber-tired rollers or loaded trucks and flat-wheel rollers.

b. Nonplastic soils. Nonplastic soils, such as sand and gravel are compacted best by vibration, as from tractors. Clean gravels are readily compacted to a dense state since the individual grains are sufficiently large to be arranged quickly in stable form. When compacting sands, special attention must be given to the detrimental effect of a slight moisture content. This may cause the grains to be held together by capillary forces sufficient to prevent them moving to a denser packing. Capillary forces can be destroyed by either complete drying or complete saturation. Drying is impractical and saturation should be employed where practicable.

126. BLANKET COURSES. Wherever the subgrade consists of plastic and cohesive soil and the base course to be laid upon it consists of coarse rock or gravel a 1-to 2-inch layer of sand or screenings should be spread upon the subgrade and rolled. Sprinkling during rolling is desirable. Such a blanket course helps prevent the plastic soil from working up into the coarse base material under traffic during wet conditions. A blanket course is not necessary if the base material is dense-graded.

127. INSULATING COURSES ON FROST-ACTION SUBGRADES. The generally accepted method of insuring stability of base course and pavement over a potential frost-action material (par. 95) is to provide sufficient thickness of *insulating material* not affected by frost action (pars. 131b and 162b). Such material should be thoroughly drained (ch. 13). Use of an insulation layer may be avoided by removing the frost-action material, particularly if it is spotty in occurrence.

128. SUBGRADE STABILIZATION. a. Purpose. Stabilization includes any process for developing or preserving stability such as admixing sand with clay subgrade, and vice versa. Commercial substances such as cement, bituminous materials, and chemicals sometimes are used in subgrade stabilization.

b. Types and evaluation. For convenience the forms of subgrade stabilization may be classified and evaluated as follows:

(1) MECHANICAL STABILIZATION. This refers to mixing and blending natural materials and compacting them at optimum moisture content (fig. 65). A common example is adding sand or other granular material to a subgrade soil high in clay. In this process enough materials are blended, mixed, and compacted to form a stabilized subgrade 6 to 9 inches thick. To justify mechanical stabilization the time and effort expended on it must be less than that needed to construct a base of imported material thick enough to provide the same wheel-load capacity.

(2) BITUMINOUS STABILIZATION. In a bituminous-stabilized soil the bitumen coats the soil particles, cements them together, and makes the mixture resistant to water absorption. Accurate control of bitumen content is required, since either insufficient or excessive amounts will affect adversely the stability of the mass (par. 96c(2)). The ideal condition for use of bituminous stabilization occurs when the natural subgrade soil is granular and approximates the gradation curves for bituminous surface courses (fig. 35). In such cases stabilization of the subgrade soil by mixed-in-place methods will result in a pavement suitable for use without additional work. In other cases the basic conditions governing bituminous stabilization of subgrades are as follows:

(*a*) It should be considered only when mechanical stabilization of soils is impractical and base course material is not available or economical.

(*b*) It should be used only when the resulting compacted mixture has a stability equal to that of a base with a California bearing ratio (CBR) which satisfies minimum requirements (table XII).

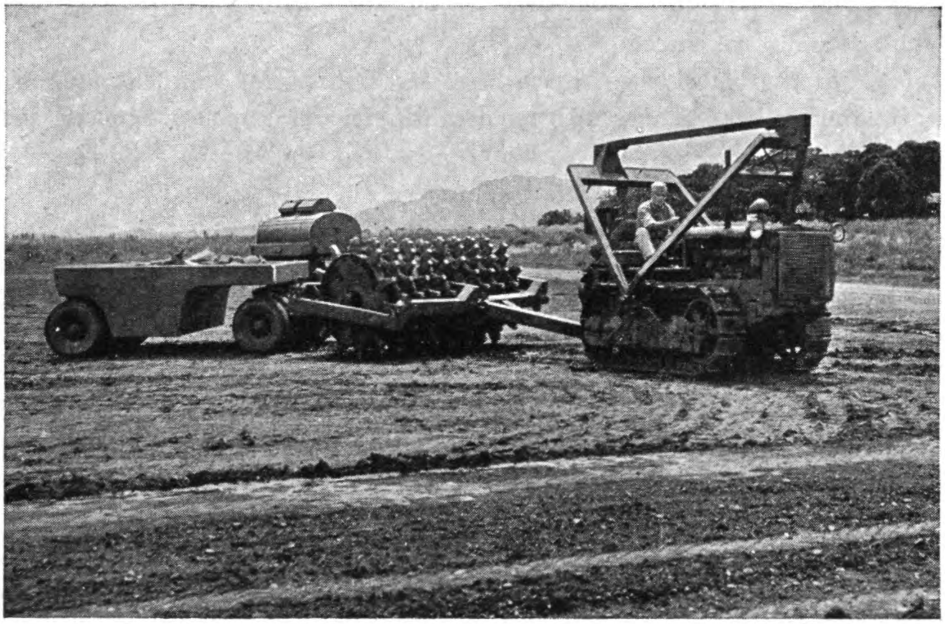


Figure 65. Sheepsfoot roller and rubber-tired roller both used in compaction of subgrade.

(*c*) Best results are obtained with granular and friable soils—those which are readily pulverized. Soils with high silt or clay content are not suitable for treatment.

(*d*) Adequate technical control is necessary for good results.

(*e*) Its use is most favorable on soils having inherent stability.

(*f*) Continuous periods of dry weather are required for mixed-in-place processing.

(*g*) Excessive moisture in the soil prohibits successful mixing and compaction.

(*h*) Cold or wet weather immediately after mixing usually requires drying the mixtures by aeration before compaction.

(*i*) This method of stabilization should not be attempted when weather conditions will retard progress seriously or affect adversely the quality of the work.

(3) CEMENT STABILIZATION. Certain types of soil may be stabilized by using an admixture of portland cement. By addition of cement to the soil and compaction of the mixture at proper moisture content, soil-cement stabilization seeks to produce a soil mass having a high resistance to displacement under all expected conditions of exposure to water and weathering action. Soil-cement stabilization should not be attempted unless conditions are definitely favorable to it. The basic conditions governing its use are as follows:

(*a*) Use only as a stabilized course directly under a bituminous wearing surface in lieu of base material with a CBR meeting minimum requirements (table XII).

(*b*) Use only granular and highly friable soils, avoiding entirely soils with high silt and clay content.

(*c*) Construct only when reasonably assured that local weather conditions will permit full compliance with requirements regarding moisture control and temperature.

(*d*) Provide adequate technical control.

(4) CHEMICAL STABILIZATION. Use of calcium chloride admixture is not recommended for subgrade stabilization but may be justified in unusual circumstances. If used, the procedure should be in accordance with methods given in standard engineering texts and trade association publications (app. VI).

(5) RESINOUS MATERIALS. Resinous compounds have been developed that aid acid soils to retain their stability as compacted at optimum moisture content. Where available they may be employed if shown practicable by field test.

c. Construction operations. (1) MECHANICAL STABILIZATION. Proportions of soil to be admixed are determined by trial mixes or by laboratory tests (par. 14, app. III). The existing surface is scarified to the depth necessary to produce the required proportion of existing material in the finished mix. The loosened material is pulverized by a combination of harrows, plow, grader, and rotary tiller. New material is spread evenly in required amounts over the pulverized material and mixed or processed by the same combination of equipment. Water is added by sprinkling as needed for optimum content during mixing. After smoothing, the layer of material is sprinkled as needed to maintain optimum content, and rolled. The type of roller is selected to suit the materials (table V). Rolling progresses gradually from sides to center of each strip, with overlapping passes, and continues until the desired compaction is obtained. After compaction the surface is shaped by light blading and rolled with flat-wheel rollers, accompanied by sprinkling as needed, until the surface is true to line and grade with a tight, uniform surface texture.

(2) BITUMINOUS STABILIZATION. Where the subgrade soil is equivalent to an aggregate the mixed-in-place method is used as described in paragraph 156. For stabilization procedures for fine-grained soils see chapter XX of the Engineering Manual prepared by the Engineering Division, Office, Chief of Engineers; standard engineering texts; and trade association publications (app. VI).

(3) CEMENT STABILIZATION. Cement-stabilized courses should be designed and constructed in accordance with requirements of chapter XX of the Engineering Manual prepared by the Engineering Division, Office, Chief of Engineers; standard engineering texts; and procedures recommended by the trade association publications (app. VI).

CHAPTER 15

BASE COURSES

129. PURPOSE AND FUNCTION OF BASES. A base course is required when the subgrade does not provide sufficient support for the loads to be carried. The quality and strength of a base course must, therefore, be higher than those of the subgrade. Where it is economical to use two or more base materials differing in quality, but each better than the subgrade, they are placed always in ascending order of quality from the subgrade upward. A base is designed to spread or distribute a wheel load over the subgrade so the unit pressure transmitted to the subgrade is less than its unit load capacity. In all cases the subgrade ultimately carries the load. (See fig. 66.)

130. TYPES. a. Selection of the type of base construction depends principally upon materials available at the particular site, but equipment available and prevailing weather conditions during construction also are important

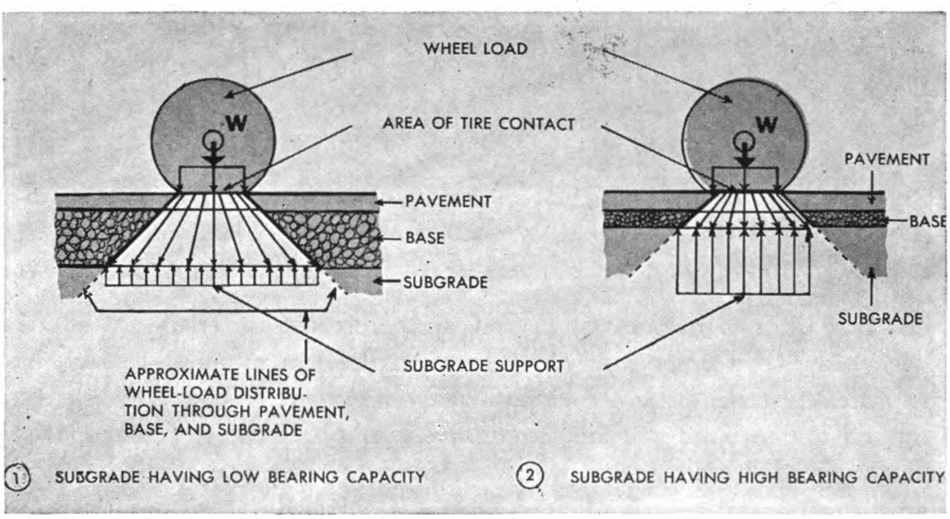


Figure 66. Unit pressure on surface approximately equals tire pressure. Unit pressure on subgrade is less than at surface because load is spread over greater area. Area on subgrade over which load is spread depends upon thickness of base and pavement. A low quality subgrade ① having a low bearing capacity requires a thick base so wheel load will be delivered to subgrade at a safe unit pressure. Required thickness of base may be reduced by building high strength into subgrade ②.

factors. A complete investigation should be made to determine the location and characteristics of all natural materials suitable for base-course construction (ch. 12). Base courses may consist of the following, singly or in combination:

(1) NATURAL MATERIALS (fig. 67). This base course is composed of specially selected natural soils, gravel, or other materials such as coral, limerock, shells, or caliche, singly or blended (par. 101a).

(2) PROCESSED MATERIALS (fig. 70). Processed materials such as crushed stone, crushed or graded gravel, and crushed limerock, which usually have high bearing ratios, are ideal for base courses directly beneath the surface (table XII). Such materials in the lower portion of thick base courses do not have definite structural advantages over materials of lower strength.

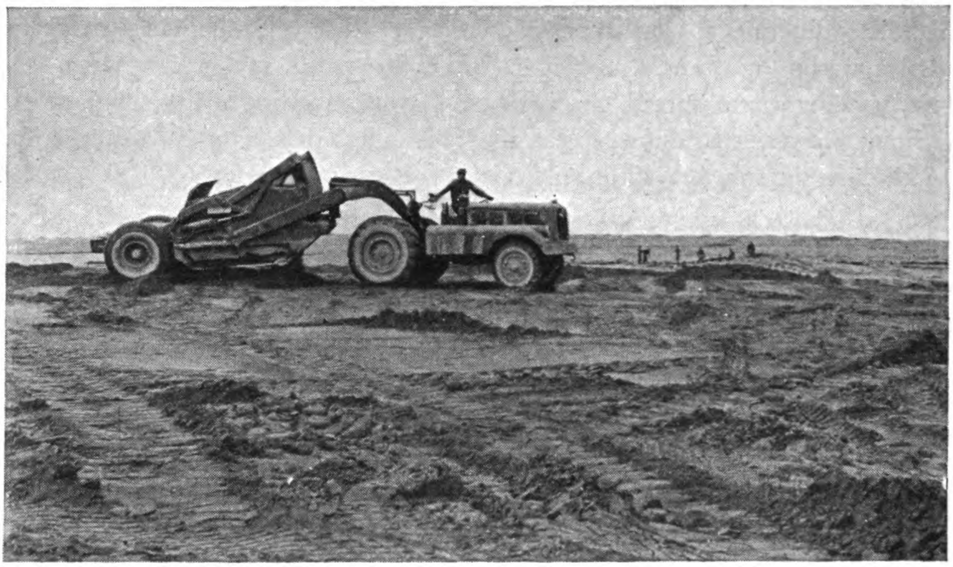


Figure 67. Spreading natural base material—volcanic cinders. (See fig. 74 for view of finished base.)

b. Base courses of selected natural and processed materials are affected less by adverse weather than any others, require less technical control, and the materials usually are locally available everywhere. They are relatively easy and fast to build and are recommended in preference to bituminous- or cement-stabilized types except where materials for such construction are definitely suitable and more readily available. If not readily available, the transportation of bituminous material or cement for base stabilization is a major supply problem in forward areas. For example, to construct a compacted cement-stabilized base, 6 inches thick, on a runway, 150 by 6,000 feet, requires about 45,000 bags or 2,100 tons of portland cement. Similarly, on the same size runway, to stabilize 6 inches compacted thickness of sand with a bituminous material requires from 1,500 to 2,000 tons of asphalt or tar products.

131. STRENGTH AND THICKNESS OF BASE COURSES—FLEXIBLE TYPES. a. General. The quality and thickness of base course required on a runway depend upon the strength of the subgrade and the size of the using airplane, as expressed by the design wheel load (table III). The basic idea is to build the most practicable subgrade, protect it by proper drainage, then provide above it only enough thickness of base, or base and pavement, to distribute the wheel load. The design should provide the necessary wheel-load capacity with the least total expenditure of time, material, and labor. For example, to justify extra effort to stabilize a subgrade there must be a greater saving of effort by reason of the reduced base thickness. In many cases it is more economical to provide extra base thickness than to gain a little improvement in subgrade support by subgrade stabilization processes.

b. Basis of design. The California bearing ratio is used for evaluating subgrades and base-course materials and for estimating the required thickness of the base. (See par. 11, app. III, for an explanation of the CBR test.) CBR values are expressed in percentages. If it is not possible to determine them for subgrade soil and base material by actual tests with the laboratory set (fig. 212), they are approximated from table V which shows usual CBR values for various classes of materials.

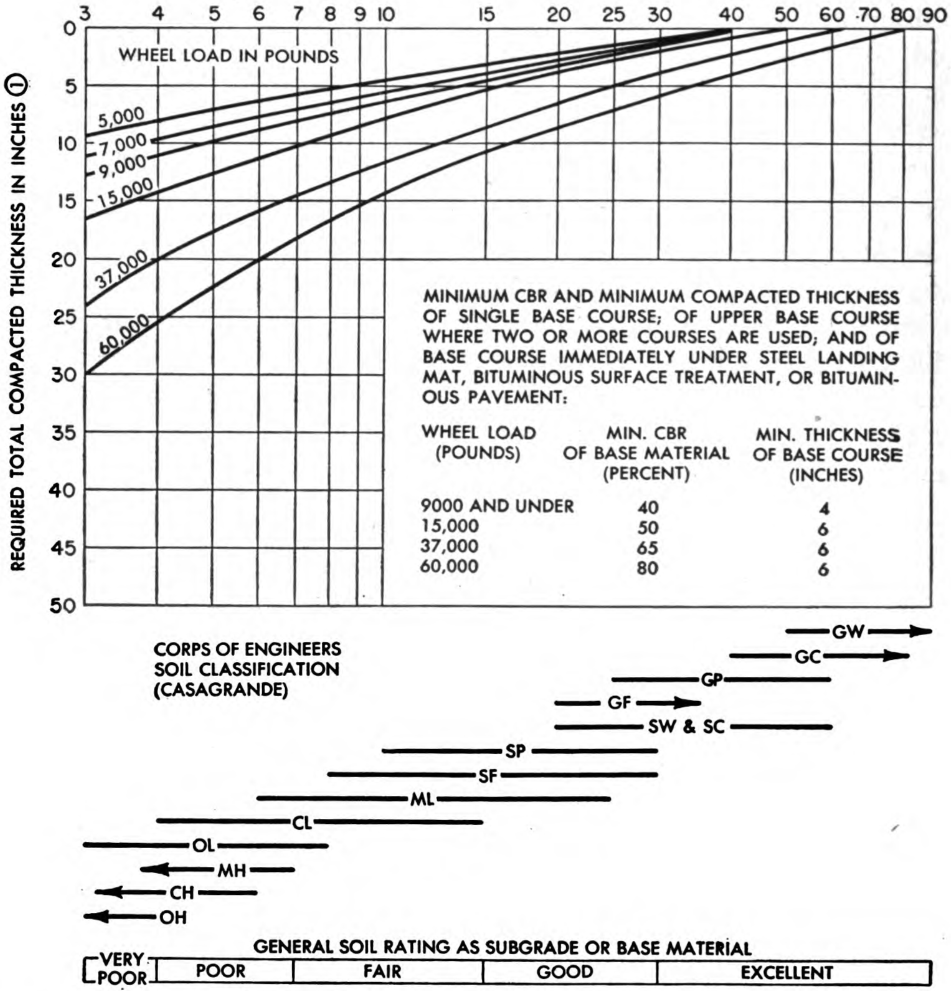
c. Moisture conditions. All subgrades, even in desert areas, gradually accumulate moisture after they are covered with a base and an impervious surface. The amount of moisture accumulation depends upon time, climatic and soil conditions, and effectiveness of drainage. For this reason a saturated condition of base and subgrade usually is assumed in designing base thickness, and CBR tests are made on saturated samples. The approximate values of CBR in table V are for saturated conditions. However, under favorable conditions of climate, soil, and drainage, and absence of ground water, the rate of moisture accumulation in a subgrade may be slow and inconsequential for 1 or 2 years, a period which may exceed the time an airdrome will be in service. Under these circumstances CBR values for saturated conditions are not warranted and a higher CBR can be assumed for design. Similarly, where a runway is for temporary service only during favorable weather higher CBR values are assumed. Where CBR values for these cases are determined by tests with the laboratory set the subgrade soil samples should have a moisture content approximately that expected during the period the airdrome is in use. In no case should a moisture content less than optimum be used. At the other extreme of severe moisture conditions, extra base thickness may be required.

d. Density and compaction. The density of a subgrade or base affects its stability and CBR value. In general, subgrades are compacted and CBR tests should be made on similarly compacted samples. The approximate values of CBR in table V are for compacted material. However, where conditions prevent compaction of the subgrade the design of base thickness should

ADVANCED LANDING FIELDS AND FIELD AIRDROMES

THEATERS OF OPERATION

VALUE OF CALIFORNIA BEARING RATIO (CBR) IN PERCENT ②



NOTE

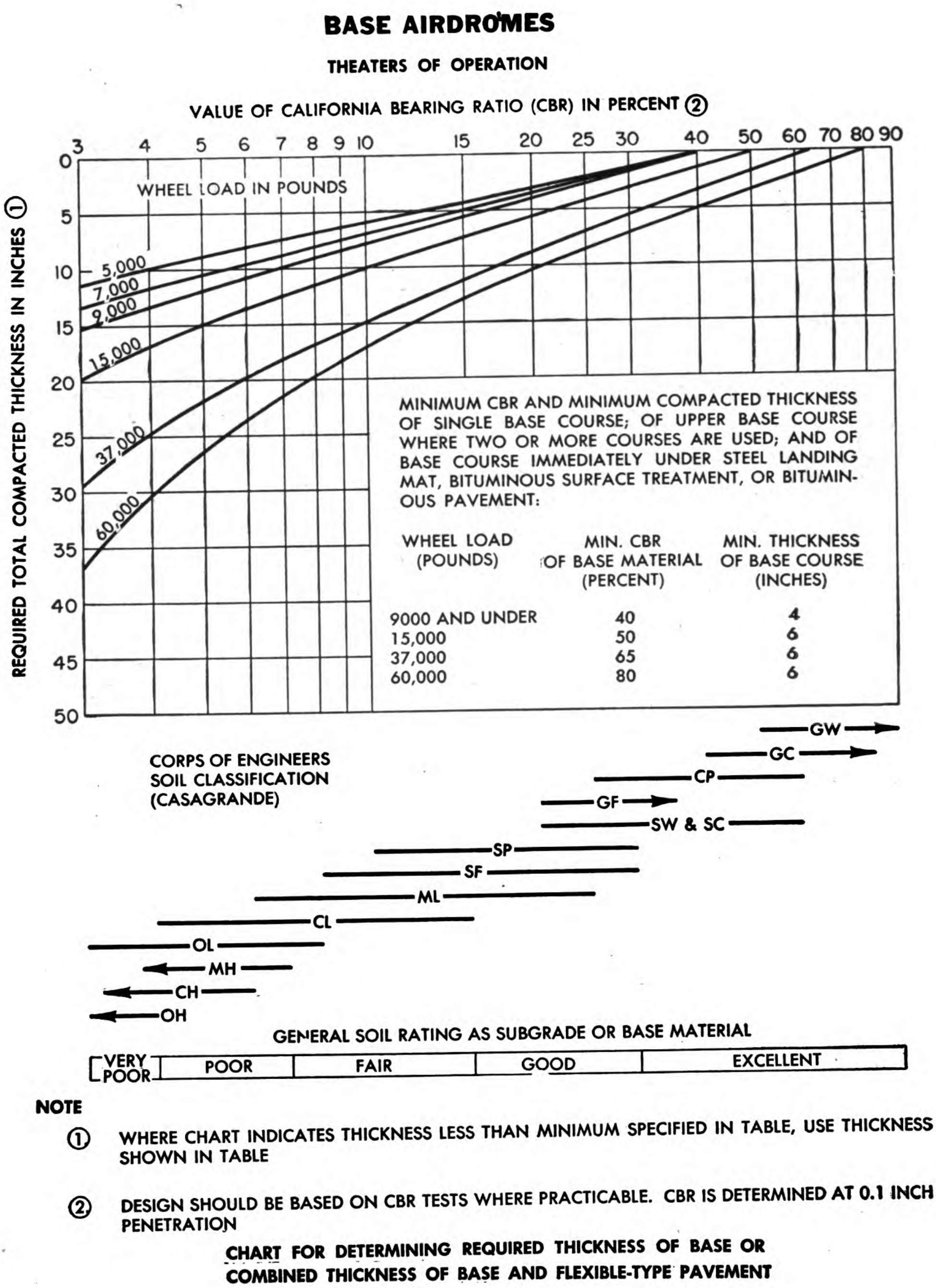
① WHERE CHART INDICATES THICKNESS LESS THAN MINIMUM SPECIFIED IN TABLE, USE THICKNESS SHOWN IN TABLE

② DESIGN SHOULD BE BASED ON CBR TESTS WHERE PRACTICABLE. CBR IS DETERMINED AT 0.1 INCH PENETRATION

CHART FOR DETERMINING REQUIRED THICKNESS OF BASE OR COMBINED THICKNESS OF BASE AND FLEXIBLE-TYPE PAVEMENT

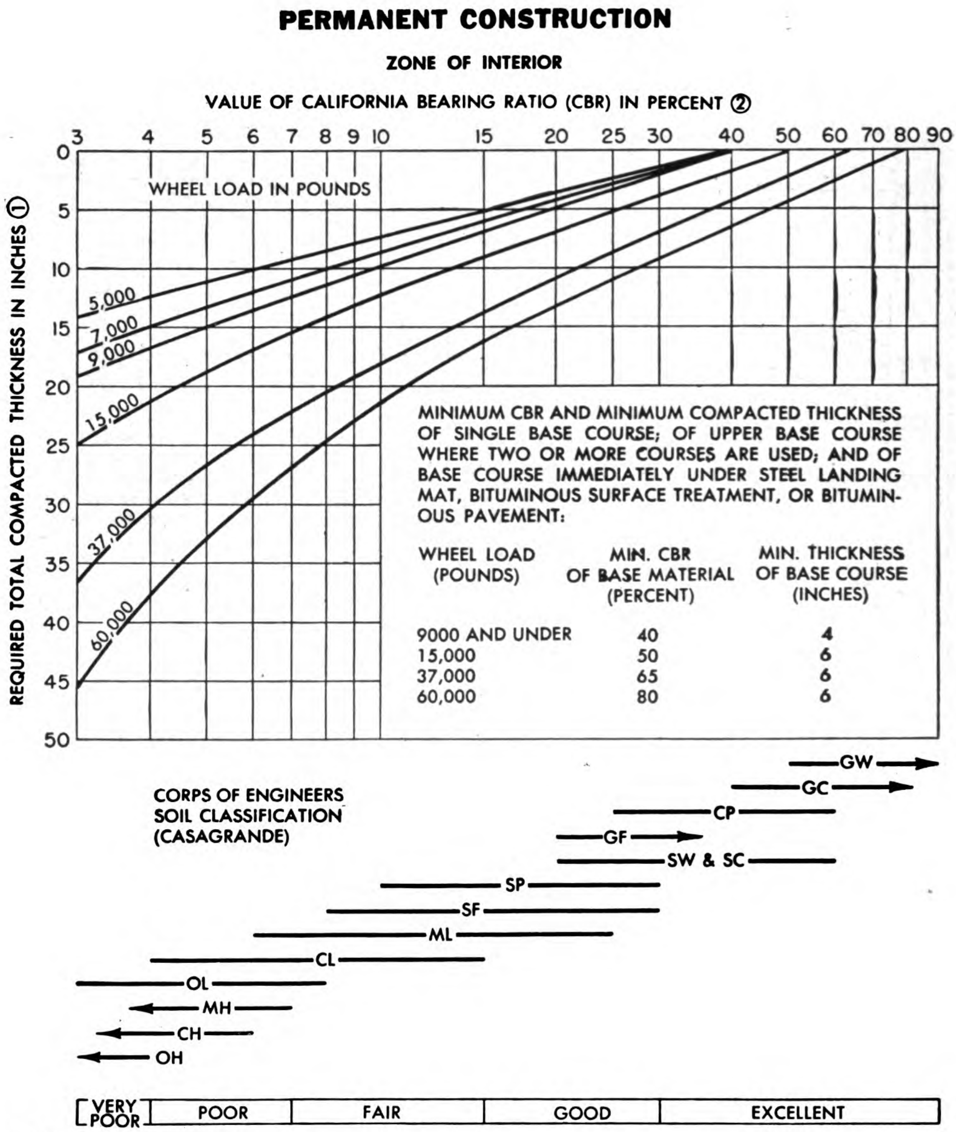
① *For advanced landing fields and field airdromes in theaters of operations.*

Figure 68. Thickness of base courses or combined thickness of base and flexible-type pavement. (See table XII.)



② *For base airdromes in theaters of operations.*

Figure 68. Continued.



NOTE

① WHERE CHART INDICATES THICKNESS LESS THAN MINIMUM SPECIFIED IN TABLE, USE THICKNESS SHOWN IN TABLE

② DESIGN SHOULD BE BASED ON CBR TESTS WHERE PRACTICABLE. CBR IS DETERMINED AT 0.1 INCH PENETRATION

CHART FOR DETERMINING REQUIRED THICKNESS OF BASE OR COMBINED THICKNESS OF BASE AND FLEXIBLE-TYPE PAVEMENT

Figure 69. Thickness of base courses or combined thickness of base and flexible-type pavement for permanent construction in zone of interior. See table XII.

be based on the CBR of the subgrade as it will exist in the construction. All base-course materials should be tested in the compacted state because bases are compacted when laid.

e. Design curves for estimating base thickness. (1) The charts in figures 68 and 69 are used for estimating the required thickness of the base except under rigid pavements. (For base requirements under rigid pavements see ch. 20.)

(2) ADVANCED LANDING FIELDS AND FIELD AIRDROMES IN THEATERS OF OPERATION. Use figure 68①. Thickness values from this chart are 65 percent of the values for permanent construction given by figure 69. Because advanced landing fields and field airdromes normally are expected to be relatively short-lived, heavy base construction is not warranted initially.

(3) BASE AIRDROMES IN THEATERS OF OPERATION. Use figure 68②. Thickness values from this chart are 80 percent of the values for permanent construction given by figure 69. Base airdromes normally are expected to serve heavy and continuous air traffic, but only for the war period. Therefore base construction should be stronger than for advanced landing fields and field airdromes, but need not be as strong as for permanent installations that are designed for a service life of 10 to 20 years.

(4) PERMANENT CONSTRUCTION. Use figure 69 to design bases for runways that are intended for heavy and continuous air traffic over a service life of 10 to 20 years, such as may be expected at installations in the zone of interior.

(5) Each curve on these charts shows for a given design wheel load the *total* compacted thickness of more stable material, including flexible pavement, required above a layer of material with a given CBR value. The 15,000-, 37,000-, and 60,000-pound curves are used for designing runways, taxiways, hard standings, and aprons; the 5,000-, 7,000-, and 9,000-pound curves for roads.

f. Use of design curves. Knowing the design wheel-load value (table III) and the CBR of the subgrade estimated from table V or determined by test (par. 11, app. III), the total required compacted thickness above the subgrade is obtained from the chart. The procedure is to enter the top or bottom of the chart at the subgrade CBR value, extend it vertically to an intersection with the wheel-load line, thence horizontally to the left, and read the required total thickness. Similarly, required thickness above any base layer is determined by reading vertically on the line representing the CBR of that base layer to the wheel-load line, then across to thickness. The total required thickness may consist of base material only or of a base course and a flexible pavement. Where a pavement is constructed, the required base thickness is found by subtracting the pavement thickness from the required total thickness indicated by the chart. No subtraction is made for bituminous surface treatments or for steel-landing-mat surfaces intended for continuous service (ch. 16). *Where the required thickness of base is less than the minimum value in table XII the specified minimum thickness is used.* If frost action is a factor, greater thickness is required. (See h below.) Where two base materials are available having different CBR values the lower part of the base may be constructed of the low CBR material, but the upper part must be of high CBR material. If this arrangement is used, the minimum thickness and minimum CBR value of the upper layer must comply with the requirements in table XII. The entire thickness may be constructed of the high CBR material because a higher CBR material always may be substituted for one with a lower CBR. However this does not permit a decrease in required total thickness because this is governed solely by the CBR of the subgrade.

Table XII. Minimum CBR values and minimum compacted thicknesses of base courses and flexible-type pavements. (Refer to figs. 68 and 69.)

Design wheel load (*pounds*)	Minimum CBR value of single base course or of upper base course where two or more courses are used[1] (*percent*)	Minimum compacted thickness of single base course, or of upper base course where two or more courses are used (*inches*)	Minimum compacted thickness of bituminous pavement[2] (*inches*)	Minimum combined thickness of bituminous pavement and base course immediately under pavement (*inches*)
9,000 and under (for roads)	40	4	2	6
15,000	50	6	1½	7½
37,000	65	6	3[3]	9
60,000	80	6	3[3]	9

[1] These values apply to the upper layer of untreated bases and to the layer of base immediately under bituminous surface treatments, bituminous pavements, and steel landing mats installed for continuous service. In emergencies and for temporary service, steel landing mat may be used on lower quality bases.

[2] These values do not apply to bituminous surface treatments or dust palliatives which, for design purposes, are considered to have no thickness. They apply only to mixed-in-place, plant-mixed, or penetration-macadam bituminous pavements.

[3] Except for base airdromes, minimum thickness may be reduced to 1½ or 2 inches, provided the thickness of the top layer of base is increased by the amount the pavement is decreased.

g. Practical test of base. Wherever possible it is advisable to construct test sections of base and observe its behavior during construction and under repeated wheel-load traffic. Conditions during the test should approximate, if possible, the average severe conditions of traffic and moisture expected in the runway. Such tests often disclose characteristics of materials that lead to an alteration of design and construction procedure.

h. Frost action. The generally accepted method of insuring pavement or base-course stability over a potential frost-action soil (par. 95) is to provide a sufficient thickness of insulating material not affected by frost action. The required thickness of base course, as determined by CBR values may not be sufficient to preclude frost penetration into the subgrade or lower zones of the base course, even though the base course material itself is relatively non-frost-heaving. In general, to insure stability the combined thickness of pavement and non-frost-action base material should be equal to the average depth of frost penetration, except the maximum required thickness in locations where frost is a factor is as follows:

Design wheel-load value (pounds)	Maximum required combined thickness of pavement and nonfrost-action base material (inches)	
	Where subgrade is fine-grained soil	Where subgrade is coarse-grained soil
15,000 and under	20	15
37,000	30	25
60,000	40	30

i. Examples. Following are illustrative solutions of thickness problems:

(1) EXAMPLE 1. A runway at a field airdrome is being designed for heavy bombers. Design wheel load, from table III, is 37,000 pounds. The base is to be given a bituminous surface treatment or surfaced with steel landing mat. Soil data are as follows:

(*a*) Subgrade soil is poorly graded sand-clay, classification SF, CBR equals 16 percent.

(*b*) One source of base material provides well-graded sand-clay, classification SW, CBR equals 30 percent. This is not suitable for the upper base course (table XII) but it can be used for the bottom course if two courses are employed.

(*c*) Another source of base material provides well-graded gravel-sand, classification GW, CBR equals 70 percent. This meets requirements for the upper base course (table XII).

(*d*) *Required:* To design the base.

(*e*) *Solution:* From figure 68①, for a wheel load of 37,000 pounds, total required thickness above subgrade having a CBR of 16 percent is 9 inches. Similarly, required thickness above the first base course with CBR of 30 percent is 4 inches. However, the minimum permissible thickness of upper base course, using the 70 percent CBR material, is 6 inches. Therefore, if the base is built in two courses using both available materials, the design must be: upper course 6 inches compacted thickness using the GW material, and the lower course 3 inches compacted thickness using the SW material. (The GW material could be used for the entire base thickness of 9 inches if more conveniently available.)

(2) EXAMPLE 2. A runway at a base airdrome is being designed for heavy bombers. Design wheel load from table III is 37,000 pounds. The

base is to be paved with 3 inches of compacted bituminous pavement (table XII). Soil data are as follows:

(*a*) Subgrade soil is fine-grained, classification ML, CBR equals 10 percent.

(*b*) Base material (coral) with CBR equal to 80 per cent is available. This is suitable immediately under a bituminous pavement (table XII).

(*c*) *Required:* To design the base.

(*d*) *Solution:* From figure 68②, for a wheel load of 37,000 pounds, total required compacted thickness above subgrade having a CBR of 10 percent is 15 inches. Since the pavement is 3 inches thick the base course must be 12 inches thick, compacted.

(3) EXAMPLE 3. Data same as in example 2 except subgrade soil is SF material with CBR equal to 25 percent.

(*a*) *Required:* To design the base.

(*b*) *Solution:* From figure 68②, the total required compacted thickness above the subgrade is 7 inches. Subtracting 3 inches, the pavement thickness, leaves 4 inches of base, but this is less than the specified minimum 6 inches for base. Therefore, the design is 6 inches of base and 3 inches of pavement.

132. CONSTRUCTION OPERATIONS. a. Operations are organized in accordance with the plan and schedule previously set up for the job. (See ch. 21.)

b. Fine grading. With a motorized or towed-type grader the subgrade is fine-graded where necessary to bring it to the designed cross section established by final grade stakes (par. 114).

c. Temporary forms or stakes. These are used to guide loose spreading of base material to uniform thickness. Forms made of random length lumber, 2 to 3 inches thick, are preferred. Their height equals the loose-layer thickness of the material to be spread. The forms are laid on edge along the sides of the runway and at intermediate parallel lines 20 to 30 feet apart. They are held in place by brackets nailed to the sides, by stakes along the sides, or by a few shovelfuls of base material banked along each side. As soon as spreading and smoothing is completed on one section the forms are pulled up and moved ahead. Where stakes are used to control spreading they should be spaced on 20- to 30-foot centers across and along the runway and driven so that their tops are at the desired height of the loose spread.

d. Loose thickness. Field-trial or laboratory compaction tests (app. III) determine the depth of loose spread required to produce a desired compacted thickness. Lacking specific data, it is assumed loose thickness will be 1.25 times the compacted thickness.

e. Hauling, placing, and spreading. Material hauled from pits or quarries by trucks, scrapers, or other vehicles is deposited on the subgrade directly from the transporting vehicle (fig. 71). Material should be dumped by a method which minimizes the amount of spreading required. Spreading is accomplished with a dozer or grader. The dozer blade is straight and at right angles to the direction of laying, the tractor running on the base at all times. The forward motion of the dozer spreads the material; by permitting the blade to drag when backing up, the desired leveling and smoothing is obtained. Spreader boxes (fig. 70) sometimes are used, or tailgate openings are restricted to control the rate of spread from trucks. Depositing and spreading of material, except macadam aggregates, should begin on each working strip at the point nearest the source. Material should be placed progressively from that point to the point farthest from the source. Hauling vehicles are routed over the spread material to avoid cutting up of the subgrade and to assist in compacting the base. This method will develop any weak spots in the subgrade, which then can be corrected promptly. Macadam aggregates are placed beginning at the point farthest from the source and proceeding progressively towards the source. Vehicles are not run over subgrades which will cut up or become rutted. This requires routing haul traffic over adjacent finished working strips and transverse

Figure 70. Processed base material being spread from truck onto runway subgrade, using spreader box.

Figure 71. Dumping, spreading, and compacting base course.

spreading of material at the point of deposit. Generally, strips are 500 to 1,500 feet long and are carried over the entire width of the runway so a portion of it can be completed for landing planes. Tactical considerations may alter this plan.

f. Water (fig. 72). During spreading and compacting operations, the base material is maintained at its optimum moisture content (par. 10, app. III) by adding water from a spray hose supplied by 2- to 3-inch pipe line and pump, or applied from a truck-mounted tank through the trailer-mounted water distributor.

Caution: Do not use the asphalt distributor as a water distributor except in extreme emergencies, as the lubrication of the pump is not designed for this use.

Figure 72. Maintaining optimum moisture content of base course during compaction. Illustration shows captured steel tank converted to construction use.

g. Compacting. Base-course layers containing gravel and soil-binder material are compacted initially with a sheepsfoot roller (fig. 224) and rubber-tired roller (fig. 223). The rubber-tired roller is particularly effective in compacting base materials where lateral movement is desired to adjust and pack the particles. Base courses of crushed stone, limerock, and shell are compacted with rubber-tired, three-wheel 10-ton, and tandem rollers. Thorough compaction of base-course layers is highly important to develop the maximum stability of which the material is capable. Equipment and methods must be adjusted on each job to suit the characteristics of the base material (table V).

h. Blending and mixing. If two materials are blended and mixed on the runway, they are spread evenly in correct proportions with the finer material on top. Initial mixing to work the fine into the coarse material may be accomplished by the scarifier attachment or by harrows. Complete mixing is accomplished with grader or rotary tiller. If water has been lost by evaporation during these operations, the deficiency below the optimum amount should be added.

i. Finishing. The motor grader (fig. 73) or rubber-tired tractor-towed grader is used for finishing graded-aggregate bases. The material is bladed from one side to the middle and back to the edge until the required lines and grades are obtained. During this operation the bladed material must be at its optimum moisture content so that, when it is rolled, it will consolidate with the other material to form a dense unyielding mass; otherwise, thin layers of the material will not be bound to the base and peeling or scabbing may result. Final rolling is done with rubber-tired and flat-wheel rollers. Figure 74 shows a finished base.

j. Special procedures for macadam-aggregate bases. (1) BLANKETING SUBGRADE. Where the subgrade soil is plastic and cohesive 50 pounds per square yard of sand or screenings should be spread, sprinkled, and rolled onto the subgrade before spreading the coarse macadam aggregate.

(2) PLACING AND SPREADING COARSE AGGREGATE. Course aggregate (par. 101c) is deposited and spread in a uniform layer of such loose depth as to produce the required compacted thickness. No layer should be more than 4 inches thick after compaction. Spreading should be from dump boards, spreader boxes, or from moving vehicles controlled to distribute material in a uniform layer (fig. 75). When more than one layer is required construction procedure is identical for all layers.

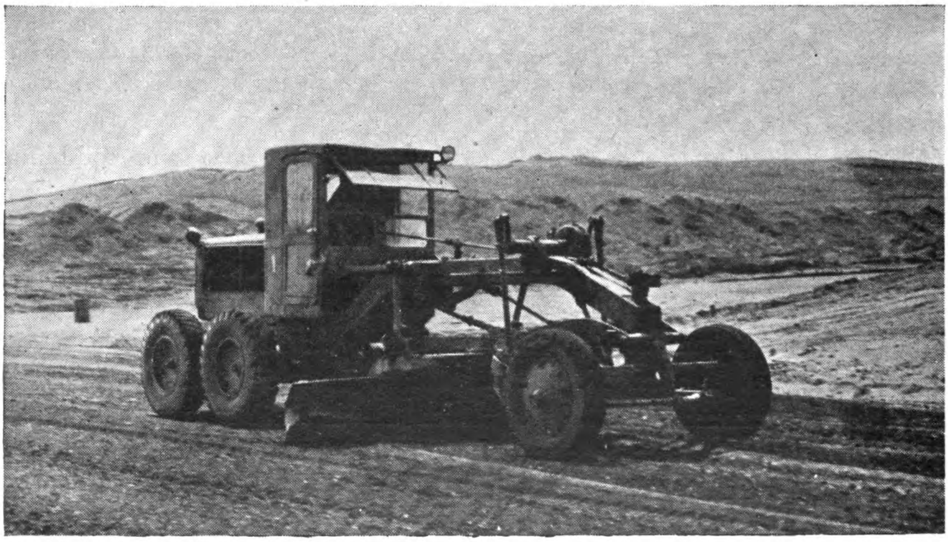


Figure 73. Finishing base course with motor grader.

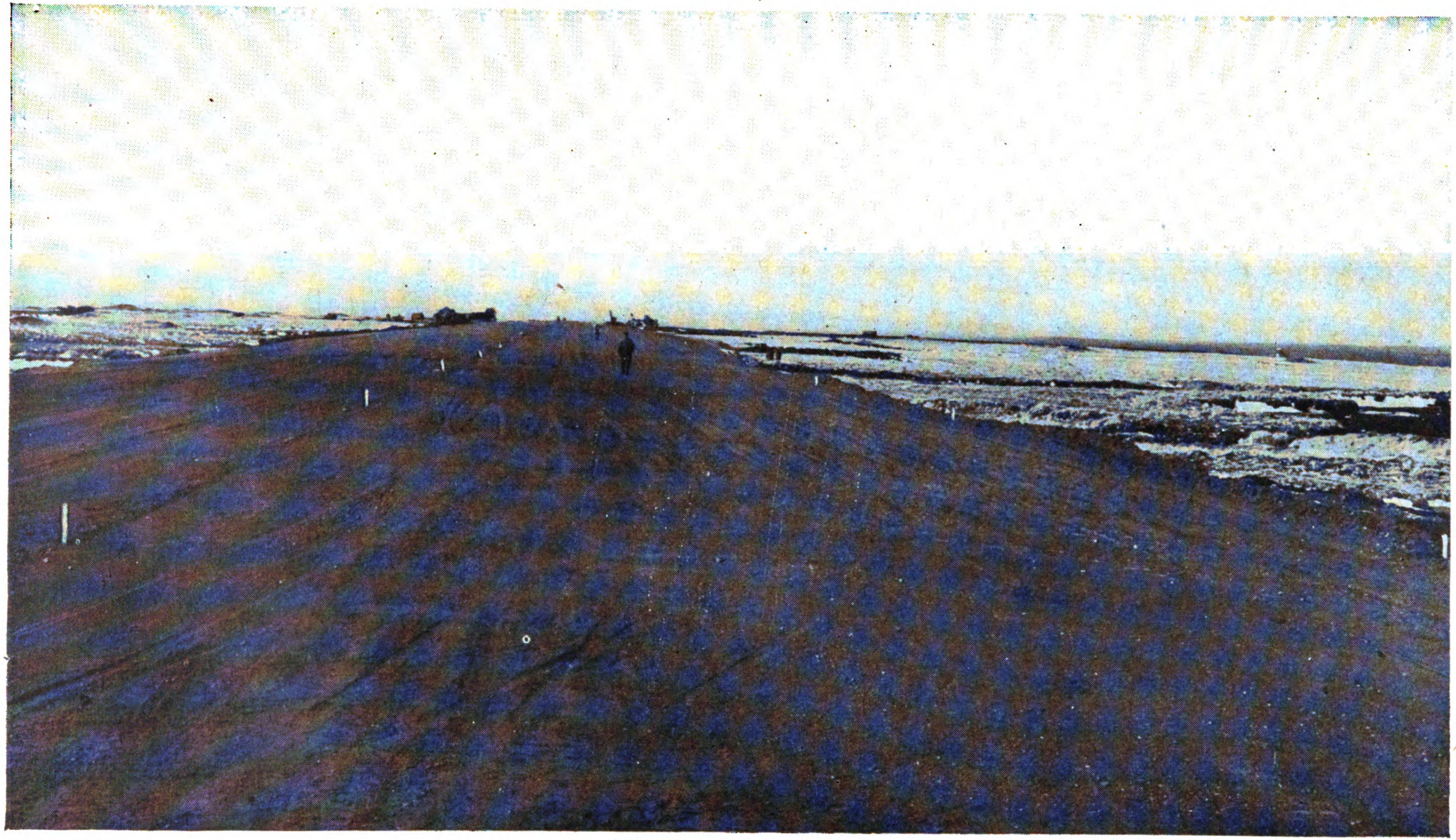


Figure 74. Finished base course ready for steel landing mat or pavement. Note stakes.

Figure 75. Macadam base course under construction.

(3) ROLLING. Immediately following spreading the coarse aggregate is compacted the full width of the strip by rolling with the 10-ton, three-wheel roller. Rolling progresses gradually from the sides to the middle of each strip and continues until the stone has been thoroughly keyed, as indicated by absence of creep or wave movement of the aggregate ahead of the roller. When due to temporary conditions, such as rain, the subgrade is soft or yielding and rolling causes a wavelike motion in the subgrade, rolling is suspended. After rolling the finished surface should have no irregularities that exceed ¾ inch when tested with a 10-foot straightedge.

(4) APPLYING SCREENINGS. After the coarse aggregate has been thoroughly keyed and set by rolling sufficient screenings are distributed to fill the voids in the surface. Rolling is continuous while screenings are being spread, so the jarring effect of the roller will cause them to settle into surface voids. Screenings may be spread in thin layers by hand shovels or mechanical spreaders or directly from moving trucks. They are not dumped in piles on the coarse aggregate. Hand or power brooms may be used to distribute them where needed during rolling. Spreading, sweeping, and rolling continue until no more screenings can be forced into the voids, but excess of screenings is avoided. The finished dry-macadam aggregate base must be true to line and grade and reasonably smooth and regular when tested with a 10-foot straightedge. In water-bound macadam con-

struction sprinkling and grouting commence after screenings have been spread. A section of convenient length is sprinkled until saturated; then rolled. Care is taken to prevent saturation and softening of the subgrade. Surface screenings are added as needed. Sprinkling and rolling continue until a grout of screenings and water forms, fills all voids, and gathers in a wave before each roller. Hand or power brooms are used to sweep wet screenings into unfilled voids. When a section of a strip has been grouted thoroughly it is allowed to dry completely before additional work is done on it.

133. TECHNICAL CONTROL. Technical control tests during construction are essential to assure desired results. Construction methods must be altered if desired results are not obtained. If this does not remedy the defect, a change of design may be required. Control tests are made to check moisture content, density obtained during compaction, gradation of mixtures, thickness, CBR values, and properties and proportions of materials. Through important, visual inspection alone is not sufficient especially for base material containing clay binder. (See par. 111f. For test procedures, see app. III.)

134. GENERAL REQUIREMENTS FOR BASES. a. The finished base must have the required compacted thickness and develop the bearing ratio (CBR) used in the design (see par. 131 and table XII).

b. All base courses must be compacted. Bases composed of graded mixtures should be compacted to 95 percent of maximum density as determined by the modified AASHO test (par. 10 and 12, app. III).

c. Base courses are built in layers no thicker than can be compacted properly. Thickness of layers generally varies from 3 to 6 inches, depending upon type of material and method of construction used.

d. Gradation of particle sizes, as determined by a siege analysis, should be within the limits specified. However, if all other characteristics, especially bearing ratio, are satisfactory, deviation from grading requirements is permitted (par. 101).

e. Base mixtures must be uniform as to grain-size distribution; there must be no accumulations in local areas of coarse or fine particles, especially soil binder.

f. The binder portion of graded mixtures—that portion passing a No. 40 sieve—must have desirable water-resisting properties, as shown by satisfactory values of plasticity index (par. 101). However, if the bearing ratio is satisfactory, this requirement may be waived.

CHAPTER 16

STEEL LANDING MATS

135. TYPES AND CHARACTERISTICS. a. General. Prefabricated steel landing mats provide a transportable, hard surfacing which is placed readily with hand tools. They are classed as heavy and light **(fig. 76)**. The

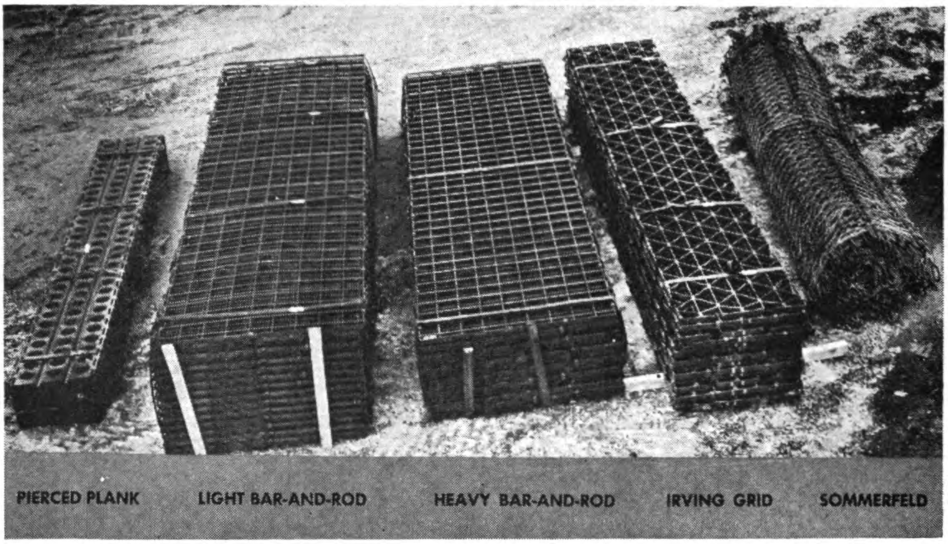


Figure 76. The five common types of steel landing mat.

heavy type is for use at airdromes from which any type aircraft may operate (fig. 77). The light type was designed for use at fighter airdromes only. Because any airdrome at times may be required to handle heavy-type aircraft—bombers and cargo planes—little use now is made of the light mats. Mats most in use are as follows (table XIII):

(1) HEAVY MAT. (*a*) Pierced plank.

(*b*) Heavy bar-and-rod.

(*c*) Irving grid.

(2) LIGHT MAT. (*a*) Light bar-and-rod.

(*b*) Sommerfeld.

Figure 77. Largest planes operate on heavy steel landing mats.

Table XIII. Characteristics and comparison of steel landing mats.

Type	Pierced plank	Heavy bar-and-rod	Irving grid	Light bar-and-rod	Sommerfeld
Weight (lb. per sq. ft.)	5.11	3.90	5.56	1.90	1.16
Unit weight and dimensions:					
Length	10'0"	12'0"	12'6"	12'0"	75'
Width	1'3"	3'0"	1'10 5/16"	3'0"	10'4½"
Depth	⅞"	1"	1"	¾"	½"
Area covered (sq. ft.)	12.5	36.0	23.24	36.0	778.12
Weight (lb.) including accesories	63.86	140.4	129.24	68.4	935
Bundles:					
Number and type of units	30 planks[1]	14 panels[2]	16 panels	30 panels[2]	1 roll
Weight (lb.) including accessories	1,928	1,966	2,067.6	2,052	935
Quantity for runway 5,000x150 ft.:					
Number of units	60,000	20,833	32,269	20,833	964
Total weight (tons)	1,928	1,465	2,084.9	712.5	440.34
Cargo space (cu. ft.)	32,084	81,222	72,092	59,084	36,111
Average laying speed (sq. ft. per man-hour)	125	65	65	125	175
Comparative camouflage potentialities	30 percent open area	85 percent open area	85 percent open area	90 percent open area	95 percent open area

[1] Breaks down into six sub-bundles of five each. One sub-bundle contains two 5-foot half-panels and four full panels.

[2] Bar-and-rod bundles are shipped in bundles of differing numbers, depending on the manufacturer. Requisitions should state required number of panels.

Figure 78. Pierced plank is the standard steel landing mat.

b. Heavy types. (1) PIERCED PLANK (fig. 78). This mat has been adopted as standard and is used to a greater extent than others. It has a bayonet-type connecting device and is locked in place with spring clips (figs. 79 and 80). Separate planks can be carried by one man, but for ease of handling two men generally are used.

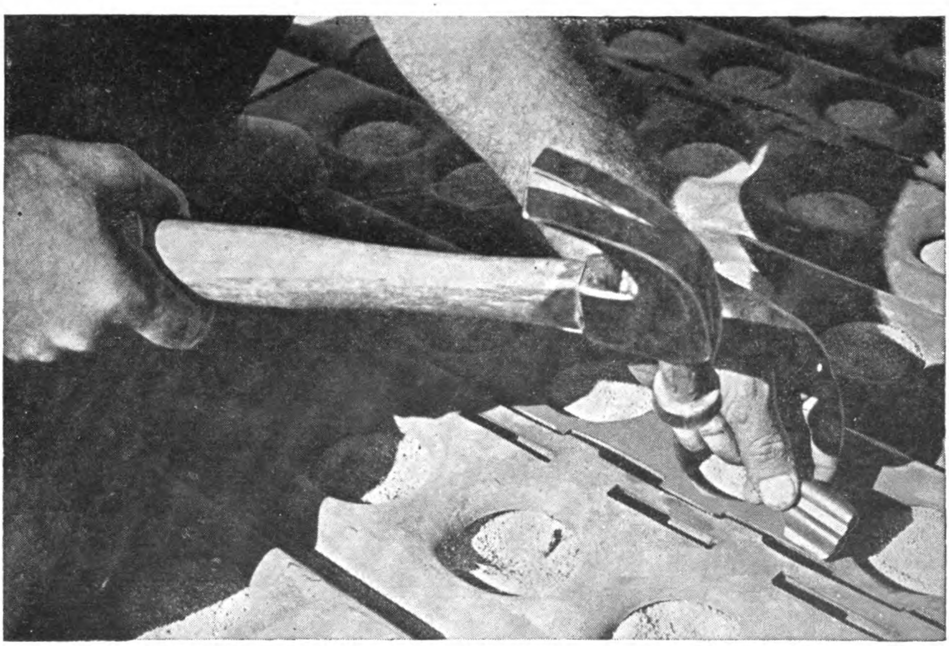


Figure 79. Spring clips are driven into slots behind bayonet hooks to lock pierced-plank panels in place.

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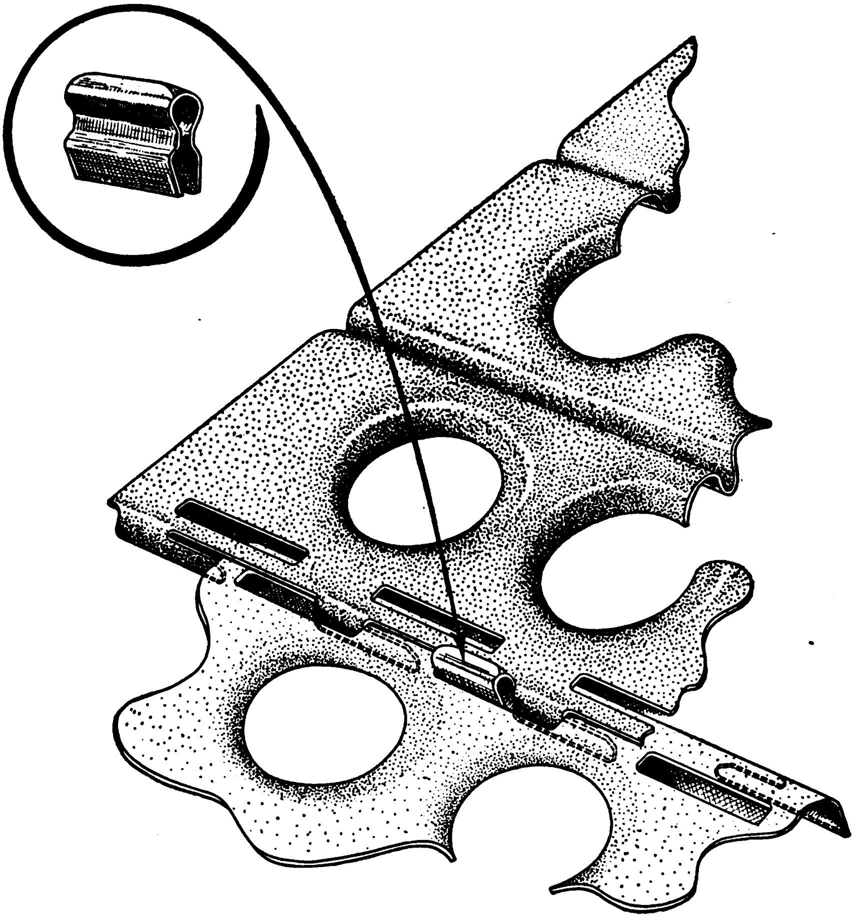


Figure 80. Details of bayonet-hook joint of pierced plan. Spring clip in second slot from end of panel.

(2) HEAVY BAR-AND-ROD (fig. 81). The panels of this mat are made with a flexible connection having a slip-ring connector. Two men are required to handle each panel.

(3) IRVING GRID (fig. 82). The connection device of this mat is a slip-ring type similar to that used on bar-and-rod mats. Two men are required to handle each panel.

c. Light types. (1) LIGHT BAR-AND-ROD. The light bar-and-rod mat is of the same general design as the heavy type with identical connecting device. Each panel can be carried by one man.

(2) SOMMERFELD. This British mat was developed for fighter airdromes. It comes in rolls approximately 10 feet wide by 75 feet long, weighing approximately 900 pounds. The edges of adjacent rolls are connected with flat steel bars, as shown in figure 83.

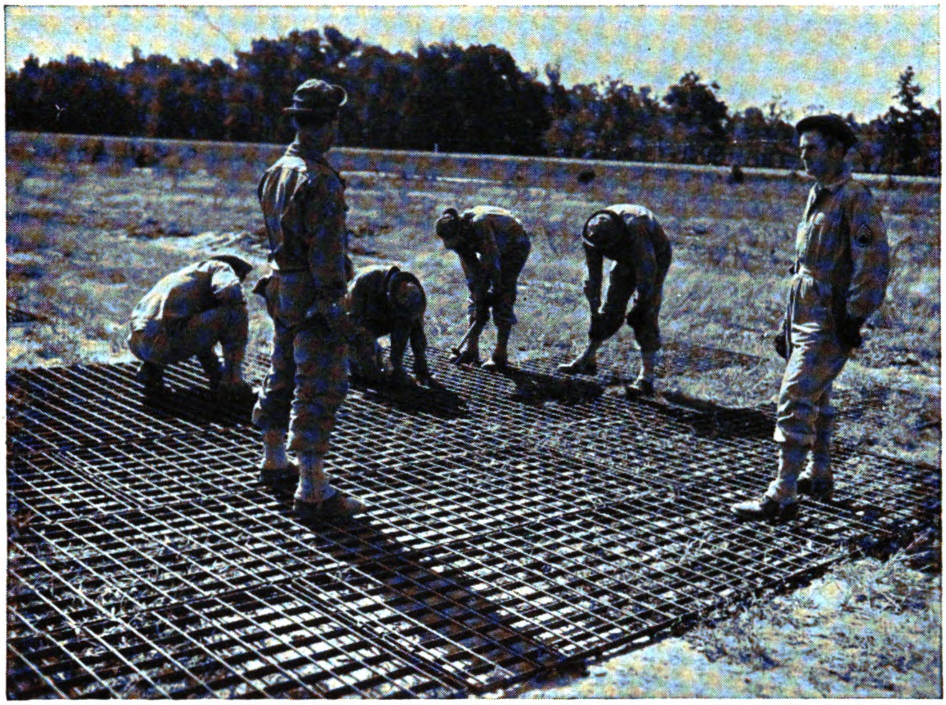


Figure 81. Laying and connecting bar-and-rod panels. Crimping crew will follow and complete connections.

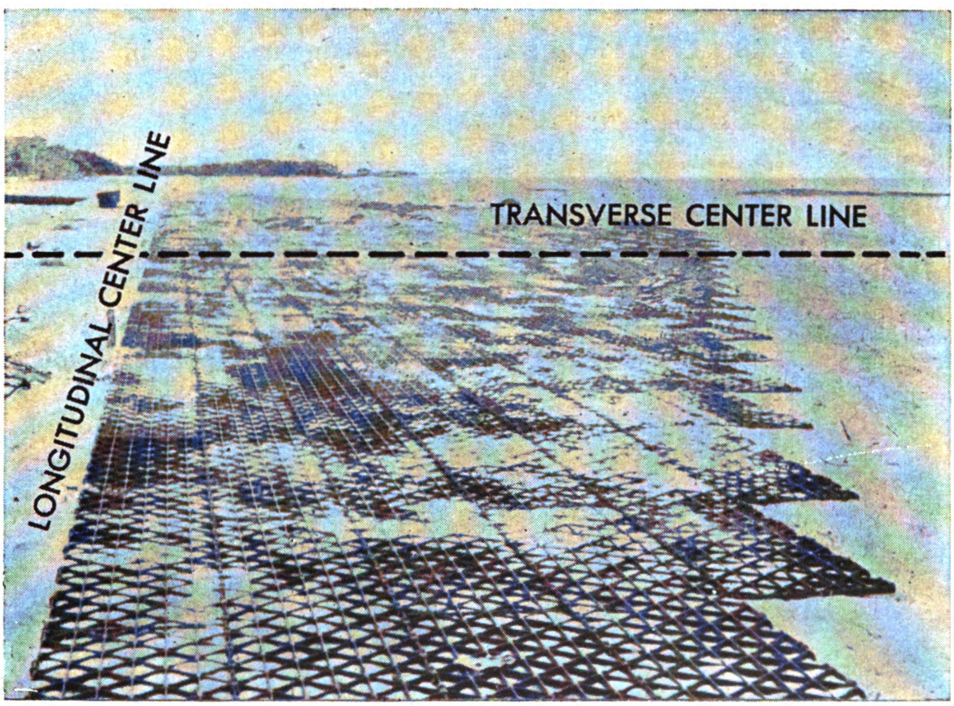


Figure 82. Laying Irving grid in echelon. End joints in adjacent row staggered approximately one-fourth panel.

Figure 83. Method of joining Sommerfeld sections.

136. FACTORS AFFECTING USE. Steel landing mats normally are used for runways where lack of time, materials, or equipment preclude usual methods of construction.

a. Time element. Where the tactical situation requires rapid construction of an all-weather runway, steel landing mats are used because they can be laid on hastily prepared bases to give temporary service until a more adequate runway can be built.

b. Lack of materials and equipment. Steel landing mats also are used to provide a surface suitable for *continuous operation* of aircraft where bituminous or concrete paving materials and equipment are not available. In these cases the mats are laid on a well-prepared base and serve all aircraft needs.

c. Base requirements. (1) GENERAL. A well-graded properly drained base is essential to proper functioning of any steel landing mat.

(2) EMERGENCY USE. In emergencies steel mats can be laid on soils with low supporting values; but continuous maintenance may be required to keep the runway usable, especially for heavy airplanes. Much more satisfactory results are obtained from sites having stable, well-drained soils. Sand in soil is desirable; a flat beach is ideal. When laid on poor soils, difficulty can be anticipated in rainy weather from mud oozing up through the interstices. The pierced-plank mat tends to become slippery when wet (fig. 84). Emer-

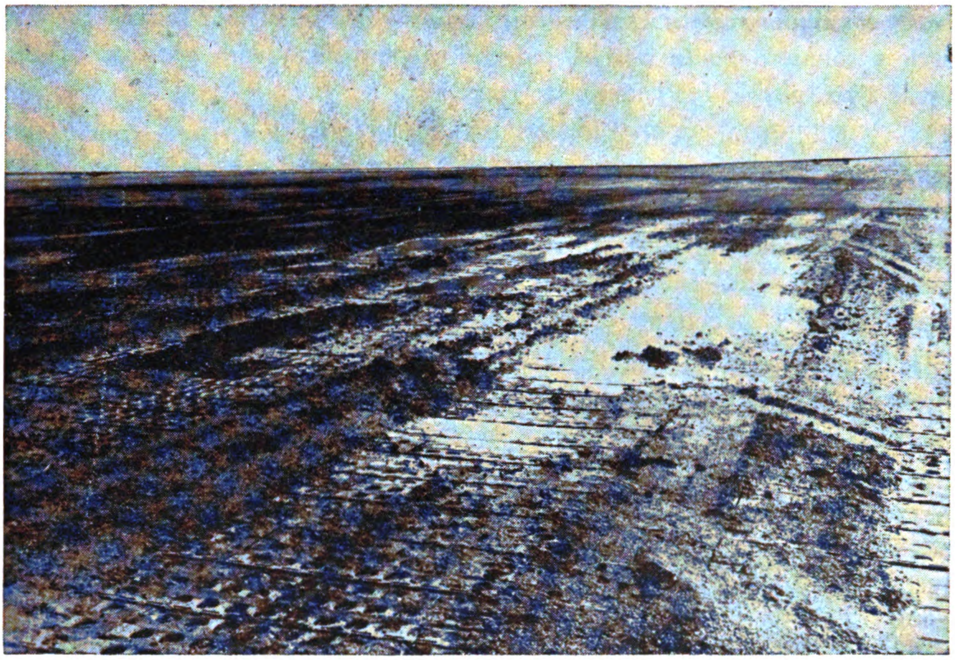


Figure 84. Poor base or subgrade results in a muddy surface when wet.

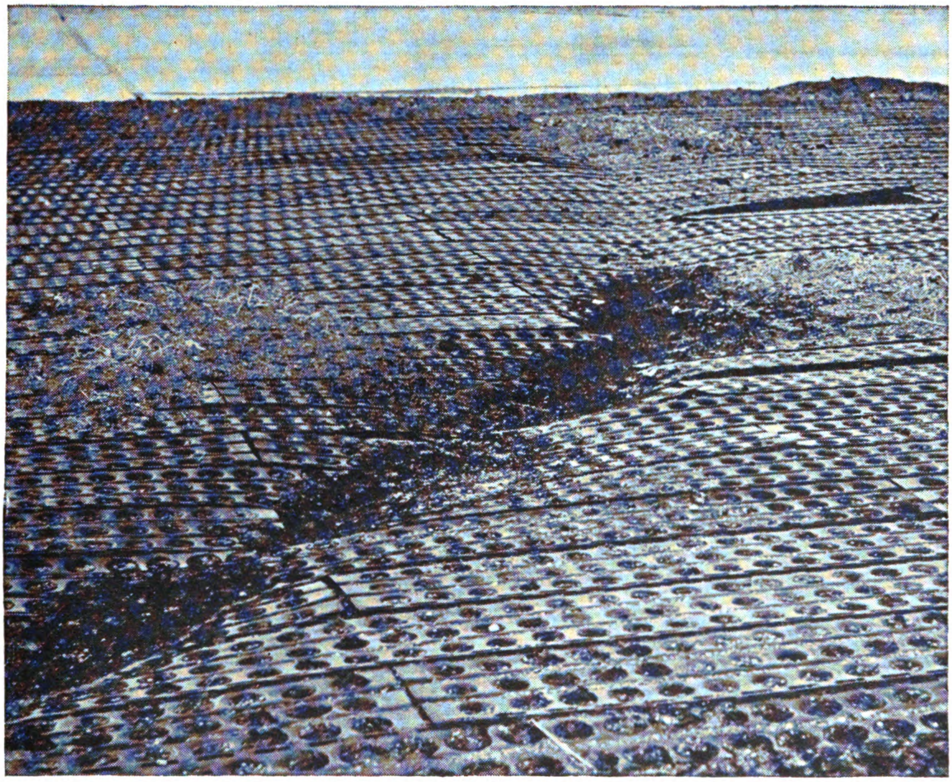


Figure 85. Weak subgrade areas result in deformed surface.

gency conditions sometimes will justify laying a mat on a poor foundation, but such a solution should not be judged in comparison with runways of the usual type suitable for continuous operation.

(3) CONTINUOUS OPERATION. Steel mat is only a surface. It serves the same function and requires the same amount and type of base preparation as any flexible pavement. Soft or yielding spots in the base cause irregularities in the mat surface (fig. 85), thereby necessitating immediate maintenance to avoid aircraft accidents. Until further test data are available base requirements given in paragraph 131 should be adhered to except in emergencies.

(4) SPECIAL REQUIREMENTS FOR CONTINUOUS OPERATION. Propeller blast will blow sandy bases from under steel mats unless preventive measures are taken. Dust palliatives of the types described in chapter 17, should be applied to the following areas:

(*a*) The last 250 feet of runway at each end.

(*b*) Hard standings.

(*c*) Alert aprons.

(*d*) Taxiways.

Where recommended palliative materials are not available expedients such as burlap and osnaburg—preferably waterproofed—old canvas, or mats of coir, straw, or long-stemmed native grasses may be used.

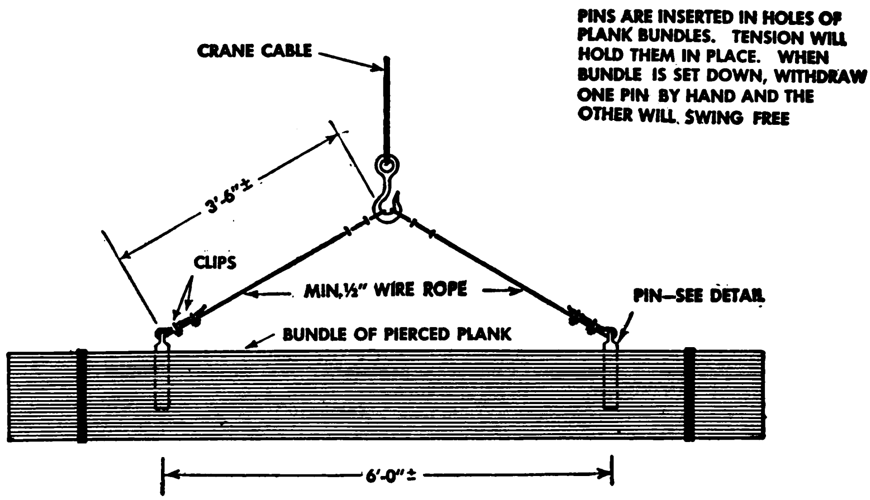
(5) DRAINAGE. Execution of drainage plans should conform to requirements given in chapter 13. All steel mats tend to retain water on the runway surface. Hence, transverse slopes should approach the permissible maximum of 2 percent.

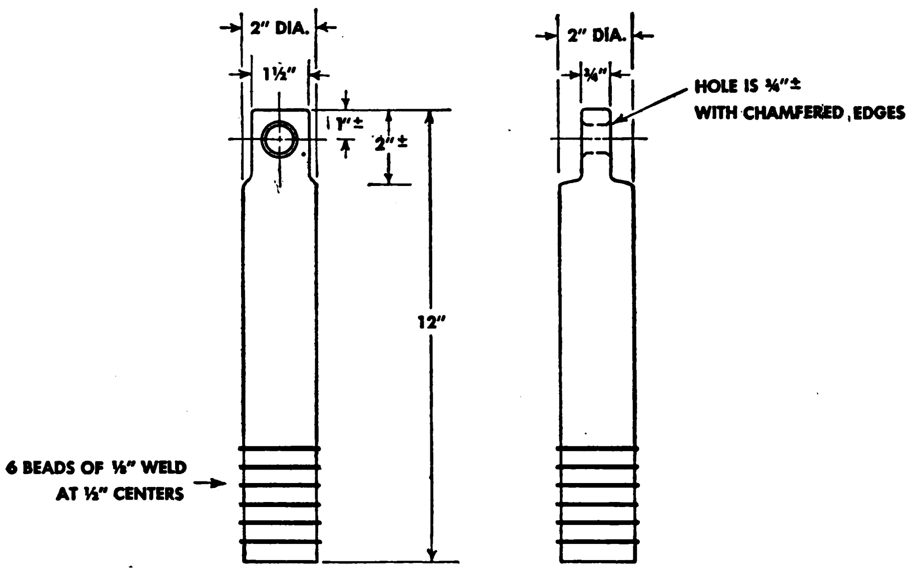
137. TRANSPORTING RUNWAY MATS. **a.** Rail shipments of mats usually are made in gondola cars. Water shipment may be by transport or barge. The panels come in bundles weighing about 2,000 pounds, except Sommerfeld mat, which is shipped in 900-pound rolls. Bundles of mats can be handled readily by the truck-mounted crane. A crane is a first priority item when mat bundles are to be handled. A special crane sling speeds the handling of pierced plank (fig. 86). Data for transportation of mats on trucks, trailers, and railroad cars are given in tables XIV and XV.

b. If the site is prepared, bundles of mats are spotted on the runway in convenient piles for distribution by hand. Bands may be broken and each panel dropped from the truck in the approximate location for connecting but ordinarily this consumes more time. Loose mats, however, should be unloaded by hand as dumping damages individual panels (fig. 87) which must be repaired (fig. 88) before being placed. Conditions may require mats to be stacked (fig. 89) near runway edges until time to lay them.

c. Sommerfeld mat should not be brought onto the runway until ready to unroll. Then the rolls should be placed accurately to save moving by hand.

DETAIL OF CRANE SLING FOR LIFTING BUNDLES OF PIERCED PLANK





DETAIL OF PIN

Figure 86. Detail of special crane sling for handling pierced plank.

Table XIV. Transportation of steel landing mats on Army trucks and trailers.

Vehicle					Pierced plank			Heavy bar and rod		
Make	Body	Bed length (inches)	Type	Capacity (tons)	Number of bundles	Weight of mat	Square feet of mat in load	Number of bundles	Weight of mat	Square feet of mat in load
Chevrolet	Cargo	108	4 by 4	1½	1	1,928	375	1	1,966	504
G.M.C.	Cargo	108	6 by 6	2½	3	3,856	750	2	3,932	1,008
G.M.C.	Cargo	144	6 by 6	2½	2	3,856	750	2	3,932	1,008
G.M.C.	Dump	144	6 by 6	2½	2	3,856	750	2	3,932	1,008
Diamond T	Cargo	133	6 by 6	4	4	7,712	1,500	4	7,864	2,016
Diamond T	Cargo	147	6 by 6	4	4	7,712	1,500	4	7,864	2,016
Corbitt	Cargo		6 by 6	6	6	11,580	2,250	4	7,864	2,016
Brockway	Bridge, low bed		6 by 6	6	6	11,580	2,250	4	7,864	2,016
Studebaker	Low silhouette		6 by 6	2½	2	3,855	750	2	3,932	1,008
Fruehauf	Machine trailer, low bed			8	8	15,420	3,000	5	9,830	2,520
Fruehauf	Machine trailer, low bed			16	15	29,000	5,625	6	11,796	3,024
Fruehauf	25-ton ponton trailer			8	8	15,400	3,000	4	7,864	2,016
Jahn	machine	302		20	20	38,600	7,500	14	27,500	7,060

Vehicle		Irving grid			Light bar and rod			Sommerfeld		
Make	Body	Number of bundles	Weight of mat	Square feet of mat in load	Number of bundles	Weight of mat	Square feet of mat in load	Number of bundles	Weight of mat	Square feet of mat in load
Chevrolet	Cargo	1	2,068	372	1	2,052	1,080	3	2,800	2,340
G.M.C.	Cargo	2	4,136	744	2	4,104	2,160	5	4,680	3,875
G.M.C.	Cargo	2	4,136	744	2	4,104	2,160	6	5,610	4,670
G.M.C.	Dump	2	4,136	744	2	4,104	2,160	5	4,680	3,875
Diamond T	Cargo	4	8,270	1,488	4	8,208	4,320	7	6,550	5,450
Diamond T	Cargo	4	8,270	1,488	4	8,208	4,320	9	8,420	6,975
Corbitt	Cargo	5	10,350	1,880	2	4,104	2,160	7	6,550	5,450
Brockway	Bridge, low bed	6	12,420	2,230	4	8,208	4,320	6	5,610	4,670
Studebaker	Low silhouette	2	4,136	744	4	8,208	4,320	10	9,350	7,780
Fruehauf	Machine trailer, low bed	6	12,420	2,230	4	8,208	4,320	11	10,300	8,560
Fruehauf	Machine trailer, low bed	6	12,420	2,230	2	4,104	2,160	6	5,610	4,670
Fruehauf	25-ton ponton trailer	8	16,800	2,970	4	8,208	4,320	14	13,100	10,900
Jahn	machine	18	38,200	6,690	10	20,520	10,800	22	20,600	17,120

Table XV. Transportation of steel landing mats on military theater-of-operations railroad cars.

Type	Dimensions	Capacity (tons)	Gauge	Pierced Plank			Heavy bar and rod			Irving grid			Light bar and rod			Sommerfeld		
				Number of bundles	Weight of mat	Square feet of mat in load	Number of bundles	Weight of mat in load	Square feet of mat in load	Number of bundles	Weight of mat in load	Square feet of mat in load	Number of bundles	Weight of mat in load	Square feet of mat in load	Number of bundles	Weight of mat in load	Square feet of mat in load
High side gondola	4'0" x 7' 6" x 23'9½"	20	Standard	21	40, 500	7, 780	13	25, 560	6, 552	15	31, 040	5, 580	8	16, 420	8, 640	18	16, 820	14, 000
High side gondola	4'0" x 6' 11" x 34'6"	30	Meter and 42"	31	59, 600	11, 620	14	27, 550	7, 056	18	37, 250	6, 700	14	28, 750	15, 120	27	25, 200	21, 100
Low side gondola	1'6" x 7' 6" x 40'5"	40	Standard	41	79, 000	15, 380	27	53, 100	13, 608	33	68, 300	12, 280	18	36, 950	19, 440	24	22, 420	18, 700
Low side gondola	1'6" x 6' 11½" x 34'6"	30	Meter and 42"	31	59, 600	11, 620	14	27, 550	7, 056	22	45, 600	8, 180	12	24, 640	12, 960	24	22, 420	18, 700
Flat	7'2" x 34' x 9⅝"	30	Meter and 42"	31	59, 600	11, 620	14	27, 550	7, 056	22	45, 600	8, 180	12	24, 640	12, 960	27	25, 200	21, 100
Flat	8'5" x 40'9"	56	Standard	58	120, 000	21, 750	27	53, 100	13, 608	57	118, 000	21, 200	18	36, 950	19, 440	30	28, 050	23, 350
Box	H 6'5" W 7'7½" L 23'9½"	20	Standard	14	27, 000	5, 250	3	5, 900	1, 512	4	8, 280	1, 488	3	6, 160	3, 240	10	9, 350	7, 780
Box	H 6'1½" W 6'11½" L 34'6"	30	Meter and 42"	20	38, 600	7, 500	6	11, 800	3, 024	8	16, 560	2, 976	6	12, 320	6, 480	13	12, 150	10, 120
Box	H 6'4¾" W 7'7½" L 40'6½"	40	Standard	28	54, 000	10,500	9	17, 700	4, 536	12	24, 820	4, 460	9	16, 480	9, 720	15	14, 000	11, 700

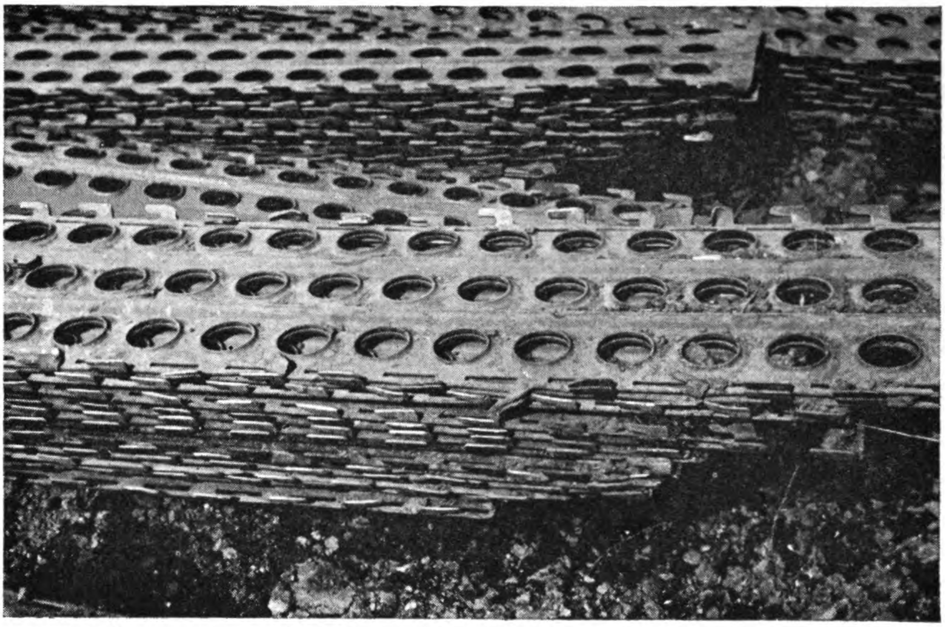


Figure 87. Panels damaged by careless handling.

Figure 88. Damaged panels being repaired by hand methods.

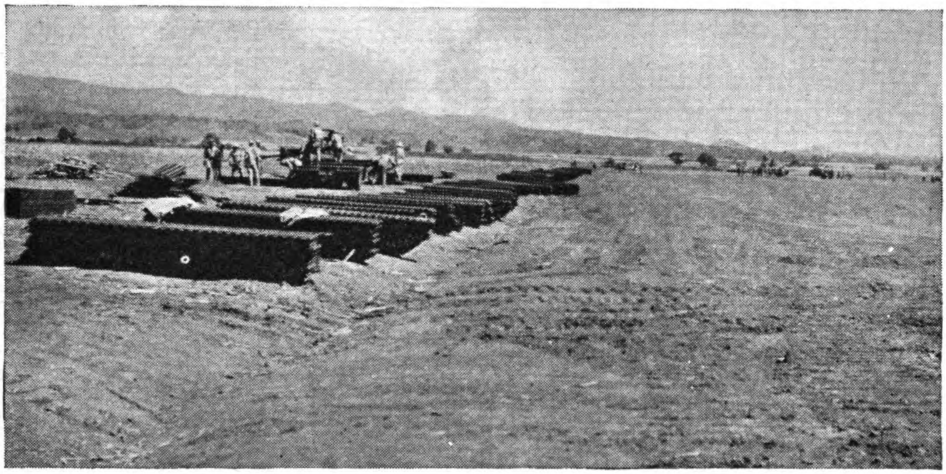


Figure 89. Bundles of panels stock-piled at edge of runway. Note wide, shallow drainage ditch.

138. SITE PREPARATION. a. General. The first step in site preparation is to establish complete drainage of the area. Most mat failures occur through saturation of the subgrade and base which results in settlement or lateral flow. The second step is to construct a properly graded and compacted subgrade or base having a minimum of surface irregularities.

b. Labor and equipment. An engineer aviation battalion normally is assigned the task of constructing an airdrome. This unit is a balanced force equipped to do such work quickly and effectively. Labor and equipment are estimated as outlined in chapter 21. In extreme cases, one platoon can lay the mat for a runway.

139. LAYING STEEL LANDING MATS. a. General. No set method is prescribed for handling and laying runway mats. The commanding officer adopts procedures best suited to do the job with available troops and equipment. Careful study and selection of methods can save considerable time and labor. The tactical situation, loading equipment available, length of haul, amount of transportation, readiness of site, and experience of troops all affect sequence of the work and the amount of handling necessary. Steel mats can be laid so much faster than the runway base can be prepared that laying should not start until at least 1,500 feet of the base are ready. Once a well-balanced organization is achieved, mat-laying progresses at a steady, predictable rate. General organization and procedure for laying any type steel mat are covered in b, c, d, and e below.

b. Alignment. Accurate lengthwise and transverse center lines are established prior to spotting material or laying mat. If the material is to be laid in echelon from one edge an accurate edge line, staked at frequent intervals, also is established.

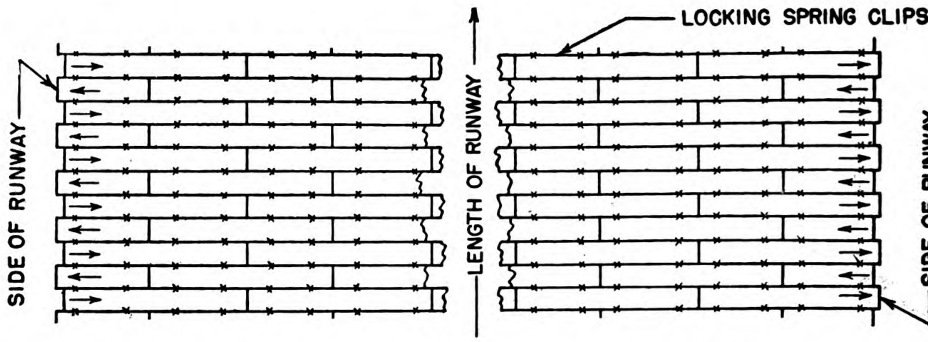


Figure 90. Partial plan of typical arrangement of pierced planks. Arrows indicate direction of bayonet hooks. X's indicate placement of spring clips. All rows of panels are laid starting from the same edge.

c. Methods. (1) With the complete site prepared, the fastest method of laying pierced plank and bar-and-rod types is to start at the transverse center line. Place two rows of panels entirely across the runway, the joints between panels lying exactly on the transverse center line and the long edge of each panel perpendicular to the lengthwise center line. Start all subsequent

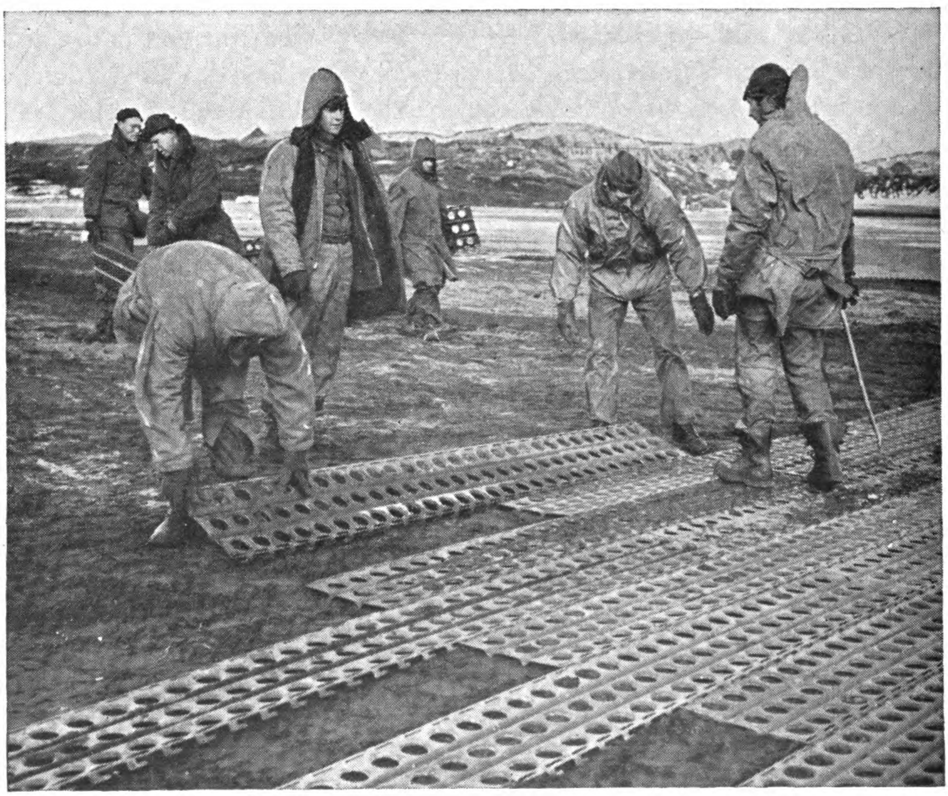


Figure 91. Laying pierced-plank panels. Reversed direction of bayonet hooks can be seen.

rows of panels from the same edge of the runway as shown in figure 90. As soon as a two-panel distance is gained additional rows can be laid in echelon in each half of the runway. In laying pierced plank, reverse the direction of the bayonet connection in adjacent rows (fig. 91) so individual planks can be removed. Check constantly the edge and transverse alignment to prevent the mat creeping.

(2) With the complete site prepared, Irving grid and Sommerfeld are started at the intersection of the transverse and lengthwise center lines. Two rows are laid along the lengthwise center line in each direction to the ends of the runway. As soon as a two-panel distance is gained additional rows in echelon can be laid in each quadrant (fig. 82).

d. Shifts. Working in shifts accomplishes laying in minimum time. Battalion organization lends itself readily to three-shift operation, one company to each shift. Headquarters and Service company transports the mats from the railhead or depot to the site and spots them as previously determined.

e. Organization of the work. Differences in mat types require varied procedures and organization for laying.

(1) PIERCED-PLANK TYPE. (*a*) The organization of a crew for laying a pierced-plank runway is outlined in table XVI. The platoon organization should be used as much as possible. The table is for panels distributed from stock piles placed at both edges of the runway. This organization is based on each crew laying one complete row of panels across the runway. Carrying details work out of stock piles at both edges, depending on which stock is nearest the laying operation. By this method planes can operate from the runway during laying. Where planes are not operating during laying, or where the base will not be cut up by trucks moving over it, it is faster and more economical of labor to stock pile panels at intervals on the runway or to distribute them from trucks directly to laying details.

(*b*) *Construction suggestions.* Keep the mat in accurate alignment by using wrecking bars to correct minor creep as it occurs. Use temporary anchor stakes (fig. 92) at the runway edge as the mat is laid, to prevent its shifting during construction. Place clips immediately behind the laying party. Change the laying crews frequently by working short shifts. Use a 6- or 8-pound long-handled sledge to drive clips, minimizing the danger from flying clips. With sufficient manpower, work can be expedited by adding working faces, using additional transverse lines at the approximate quarter points of the runway. To assure breaking of joints and opposing direction of bayonet hooks at junctions, the distance between any two transverse lines must be an odd multiple of 1.25 feet, the width of a panel. Junctions between working parties then should occur at panel points. If panels cannot be made to meet, they must be welded at the junction. Junctions or angles in taxiways are handled in the same way (fig. 93).

Where welding is required at a junction unused bayonet hooks on overlapping panels should be burned off to get a smooth surface at the weld. Long pieces

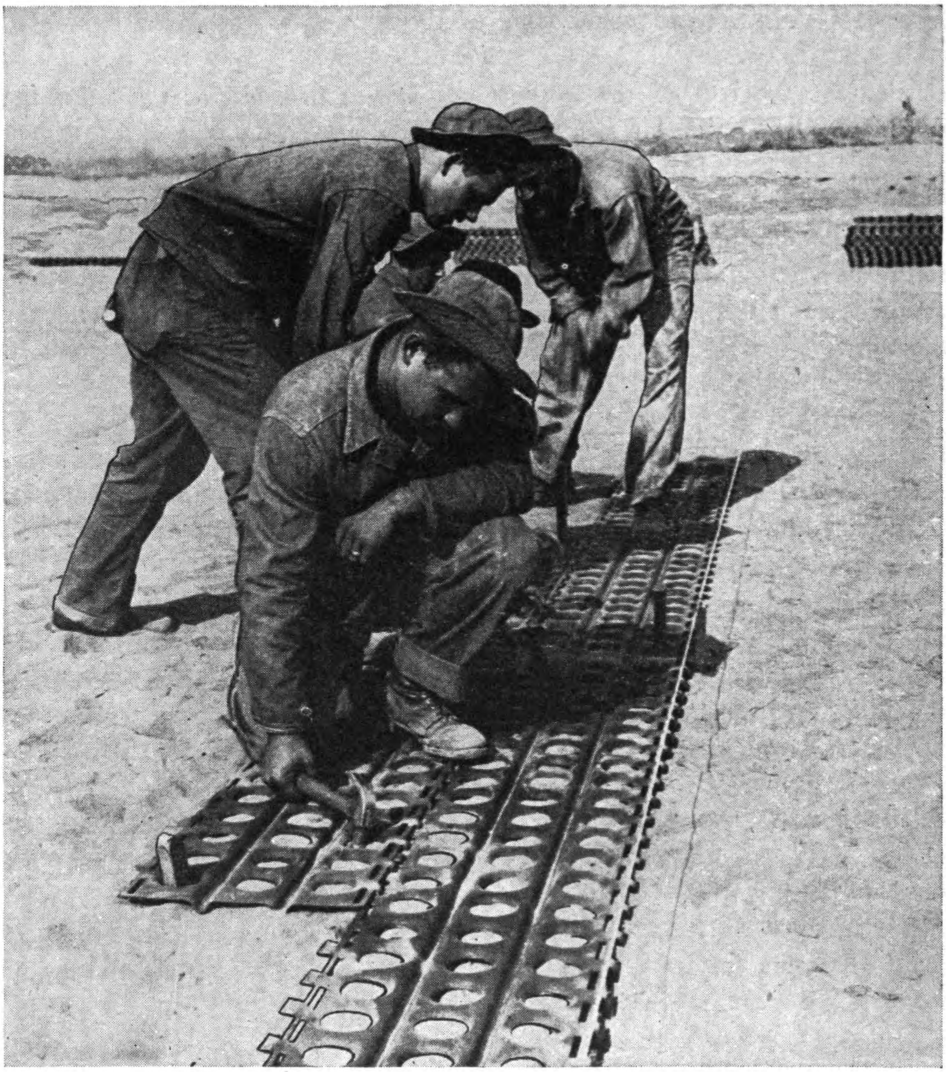


Figure 92. Temporary staking of panels assists in alignment.

of steel rod shaped like hay hooks are valuable in handling and laying panels (fig. 94).

(2) *Bar-and-rod type and Irving grid.* (*a*) The *placing crew* consists of four men. These men cut bundles straps and carry panels from stock piles to their approximate position in the runway. As many placing crews are organized as there are men available. The maximum number of men should be used to get the mat laid on the ground as soon as possible to avoid delay by bad weather, poor transportation, or other adverse factors.

(*b*) The *laying crew* (fig. 81) consists of four men two designated as end men and two as band men. The two end men hold the panel about 18 inches above the ground while the two band men move the connector bands quickly to positions which allow the panel to be brought against connectors of the adjacent panel without interference. *Panel and joints should be staggered* so they are opposite the middle of the adjacent panel (fig. 95). The panel then is placed into exact position without sliding it on the ground and dislocating the connector bands (figs. 96 and 97). The two end men hold the panel firmly against the adjacent panels while the two band men fasten the end connector and one side connector at each of the inside corners of the panel. This crew does not crimp these bands or fasten the other connectors of the panel. One laying crew should be provided for each row being laid in echelon. Additional rows can be started as soon as the preceding crew is two panels ahead.

(*c*) The *crimping crew* should be a normal work unit, such as the squad, having enough men to drive the bands into place and to crimp them as fast as the mat is laid. If standard crimping tools and ball peen hammers are not provided, ordinary hatchets can be used to drive and crimp the bands. Every band must be crimped tightly (fig. 97). Other men at work should stay out of the way of the laying crew.

Table XVI. Organization of a typical laying crew for pierced plank

	Noncomissioned officers	Men
Carrying crew		
1 Noncommissioned officer in charge	1	
5 Carrying parties, 2 men each		10
1 Stock-pile party, 2 men, break bundles, help handle panels		2
Total	1	12
Laying crew		
1 Noncommissioned officer, in charge*	1	
1 Noncommissioned officer, assists laying, checks alignment	1	
1 Party hooking mats, 2 men		2
Total	2	2
Clipping crew		
1 Noncommissioned officer in charge*	1	
1 Clipping party, 2 men		2
1 Man supplying clips		1
Total		3
Miscellaneous crew		
1 Noncommissioned officer, in charge*	1	
4 men rake ahead of mat laying, stake mat to prevent creep, do odd jobs		4
Total		4
Grand total	3	21

* General supervision.

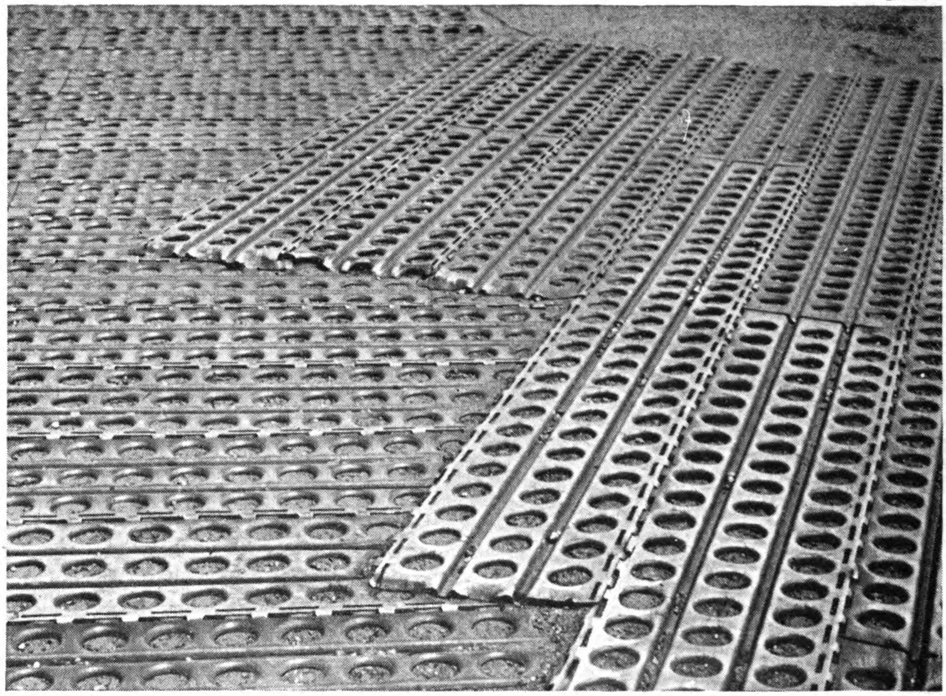


Figure 93. Junction in taxiways with panels overlapped and welded.

(3) *Sommerfeld type.* (*a*) The *placing crew* should consist of one work unit such as the platoon. It does the various operations of unrolling and aligning rolls, threading bars, and inserting fishplates. Rolls should not be dragged on the ground as this tends to disturb the mesh and bend the transverse rods. When a roll has been dumped accurately into place four or five men cut the banding wires and unroll it. The ends of the rolls then are overlapped 8 inches and connected with the wire loops or buckles provided. Where wire loops are used the weld of the twisted loop should be placed under the mat so, if it is fractured, sharp ends of the wire will not form a hazard to tires. Unrolling should be done in a forward direction to avoid unnecessary injuries to the men and their clothing. Passage of the men over the mat helps flatten it. The stretching crew, in the meantime, attaches a 2- by 6-inch improvised wood stretching bar to the far end of the roll and pulls slightly with a truck to bring the roll into alignment. Lengthwise bars then are threaded into the loops of the transverse rods to link the whole runway together (fig. 83). When the bars have been laid along the joint it can be seen which loop a bar should enter for threading. This also permits any number of lengthwise bars to be inserted and threated simultaneously. When pushing the bar through the loops by hand becomes difficult a sledge hammer may be used. A short bar with a slot in one end may be improvised to hold a loop vertically for easy threading. To provide for temperature expansion a ¼-inch space should be left between ends of the threading bars. The fish

Figure 94. Method of laying pierced plank. Bayonet hooks of raised panel are inserted into slots of panel already laid. Note use of short planks at ends of alternate rows to obtain staggered joints.

plates are inserted next. The end of one roll need not align with that of the adjacent row if length of rolls varies.

(*b*) The *stretching crew* consists of two groups, one for lengthwise and the other for transverse stretching. Only two men and a truck driver are required

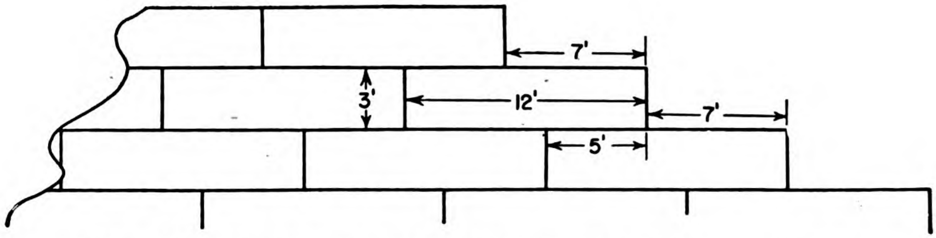


Figure 95. Partial plan showing method of staggering bar-and-rod panels.

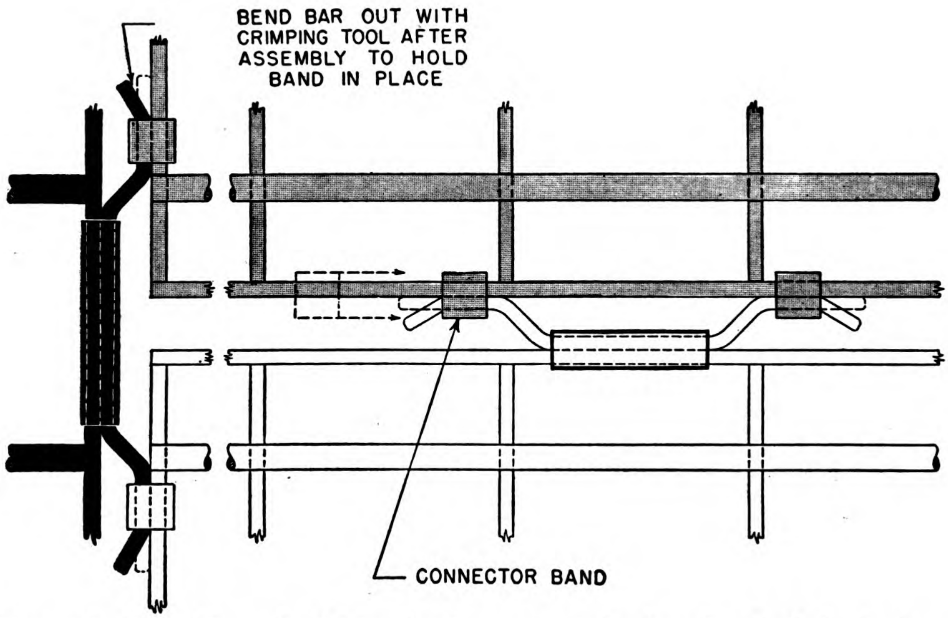


Figure 96. Plan of bar-and-rod joint showing connector bands and method of crimping.

Figure 97. Joint in bar-and-rod mat with crimping completed.

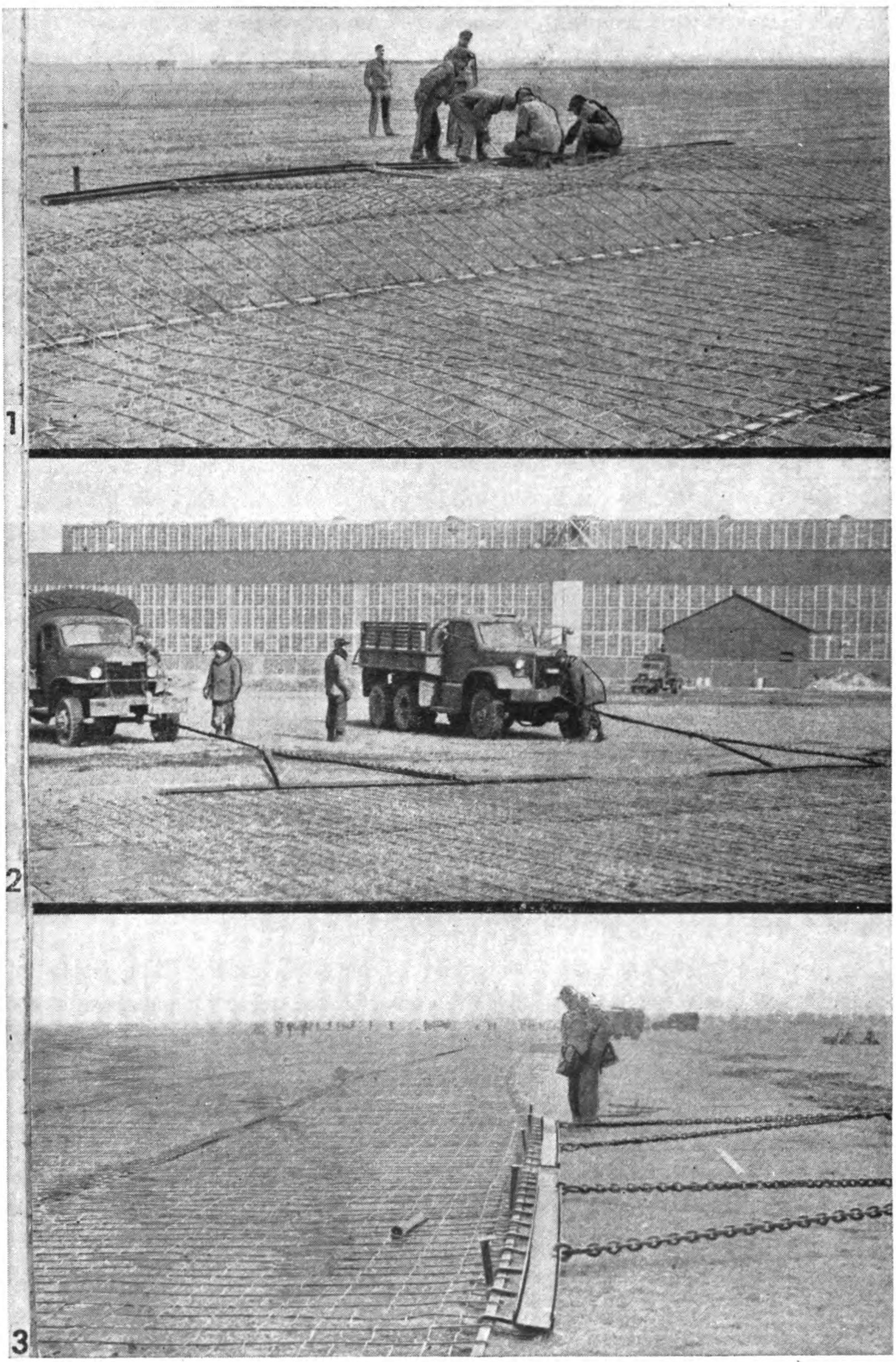
for each lengthwise stretching group, one of which is required for each laying crew. The transverse stretching group should consist of at least ten men and two truck drivers. Two such groups are necessary for a runway. The rows are laid in echelon from the center to the edge of the runway, and stretching may begin as the edge row is laid. For stretching, the center row of the landing mat must be staked temporarily at 3-foot intervals. The transverse stretching groups stake and stretch the mat with trucks and stretcher bars, as shown in figure 98. To expedite stretching these groups should work side by side on one edge of the runway. After the stretching bar is attached to the edge of the mat a pull of about 7 tons is exerted on it by a winch or tractor at an angle of about 85° from the line of the runway. Temporary pickets are placed behind the bars to hold the tension and the process is repeated. Permanent pickets then are driven at about 3-foot 4-inch intervals along the edge, and the temporary ones removed. Pickets should be started at an angle and driven so as to tighten the mat as they go down. It has been found impracticable to try to stretch in one operation the whole width of a runway laid over turf.

f. Panel connections. (1) All steel mats should be laid to get staggered or broken joints. Pierced-plank panels are laid so that the joint between two panels in the same row is opposite the midpoint of the panels in adjacent rows (fig. 90). Bar-and-rod panels are assembled as illustrated in figure 95.

(2) Irving grid and bar-and-rod panels are joined by connector bands (figs. 96 and 97). The bands encircling the outside bar of a panel are slid over the tips of the connector opposite on the adjacent panel. To complete the connection both tips of each connector are bent back so the connector bands cannot slip off. To remove a single panel when the mat is laid, straighten the connector tips and slide off all bands holding it.

(3) Pierced-plank panels are connected by bayonet hooks. The hooks of each added panel are inserted into the slots of the adjacent panels and the new panel moved in the direction the hooks point until they are completely engaged (fig. 80). Then spring clips are driven behind the hooks into the cleared portion of one slot near each end of the 10-foot panel to prevent the hooks from sliding back and becoming disengaged. Panels must be laid with hooks pointing in opposite directions in adjacent rows, so that individual panels can be removed. Four spring clips per side per panel are required for best results. In addition to the two clips mentioned above, the two clips placed at similar points on adjacent panels bring to four the number on each side of each panel (fig. 90).

g. Finishing ends of runway. A trench is excavated at each end of the runway across the entire width occupied by the steel mat. The mat is laid down the slope of the trench about the width of six panels, as shown in figure 99. After the mat is in place the trench is backfilled and the fill compacted. This method of end finish tends to reduce creep and curling at runway ends.



① *Loose mat which has been stretched lengthwise only.*

② *Applying 7-ton pull to stretcher bars.*

③ *Temporary pickets in place. These will be replaced with permanent stakes.*

Figure 98. Steps in transverse stretching of Sommerfeld mat.

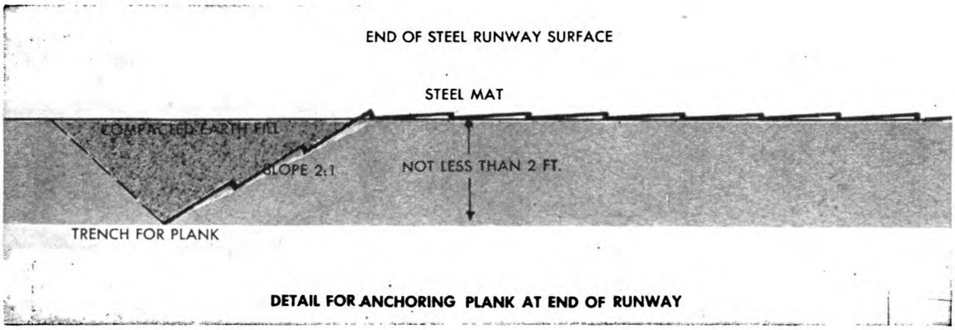


Figure 99. Method of anchoring mat at end of runway.

h. Finishing sides of runway. Half-panels of pierced plank, shown in table XIII, normally are used to finish the sides of the runway to an even line (fig. 94). When sufficient half-panels are not available they can be made by cutting full panels in half. When finished to an even edge, curling of panels at edges may be overcome by anchoring the mat with cables or racked wire to deadmen buried at the side. The mat may be anchored at the side by omitting the half-panels, bending the extending portions of panels downward into a trench, and backfilling the trench (fig. 100). A device for bending panels is shown in figure 101.

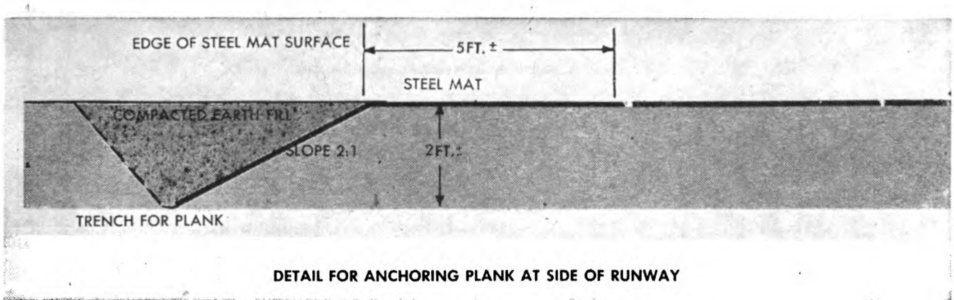


Figure 100. Method of anchoring mat at edge of runway. Approximately one-half of panel is bent down and buried in the trench.

i. Rates for laying and required quantities. The rates of laying a mat, given in table XIII, are average production figures. Especially favorable or unfavorable conditions will result in marked changes. Quantities of mat required will vary with length and width of the runway, length of taxiways,

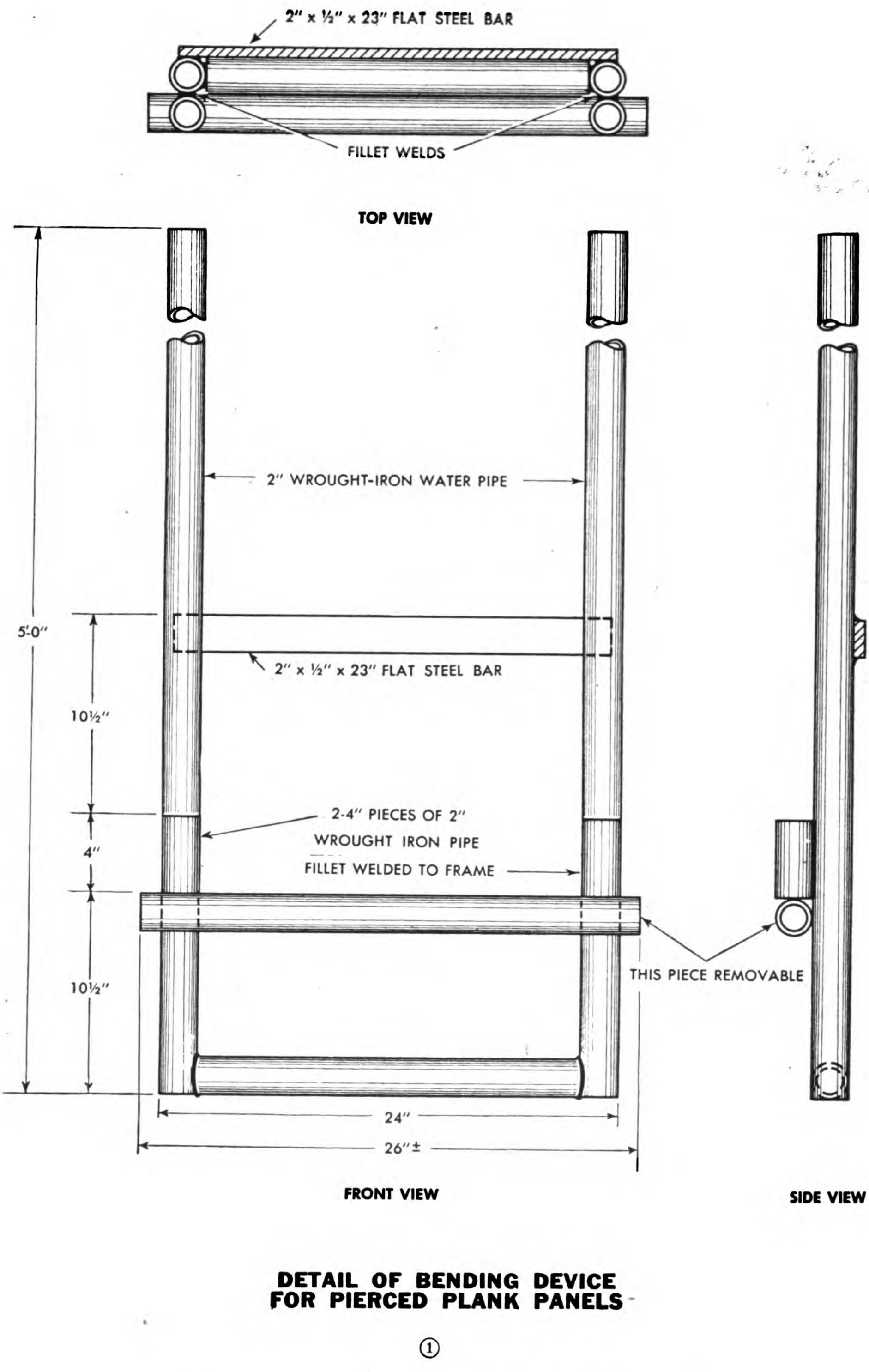
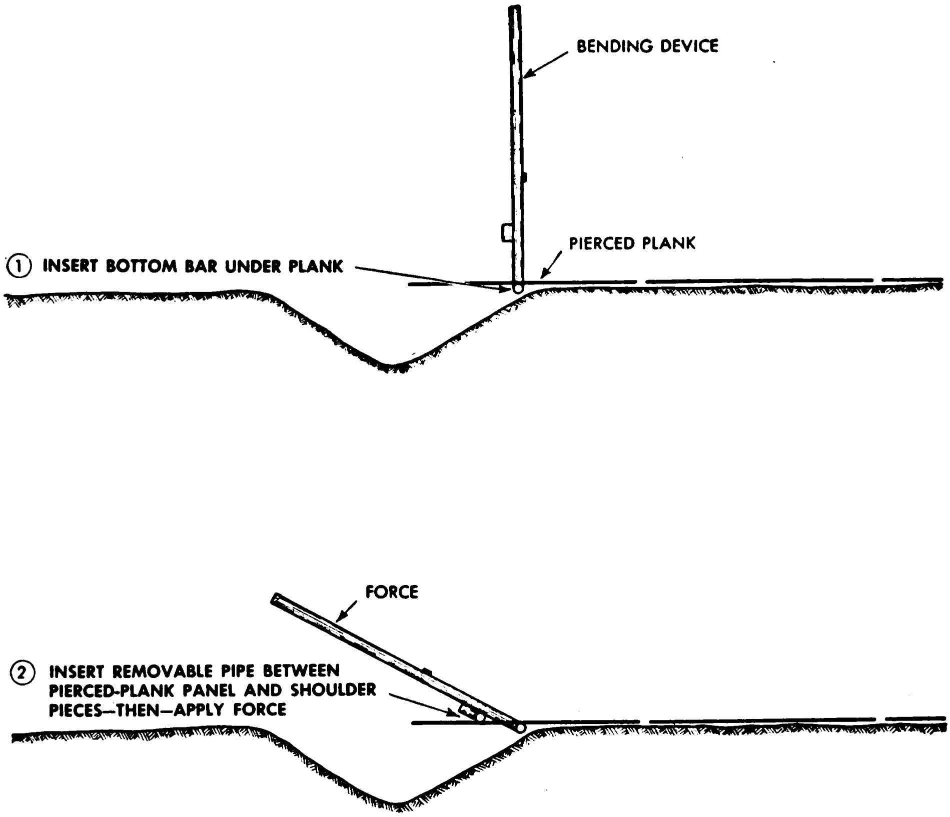


Figure 101. Device for bending pierced plank panels.



METHOD OF USING BENDING DEVICE

②

Figure 101. Continued.

and number of hard standings. A tabulation showing figures for a typical installation of pierced plank follows:

Runway, 150- by 5,000-foot	750,000 sq. ft.
Taxiways (including stubs) 50- by 10,000-foot	500,000 sq. ft.
50 hard standings—100- by 100-foot	500,000 sq. ft.
Total area to be surfaced	1,750,000 sq. ft.
Area of 1 panel	12.5 sq. ft.
Number of panels required	140,000

Laying time required:

Runway (125 square feet per man-hour, see table XIII) 750,000 ÷ 125 = 6,000 man-hours.

Taxiways and hard standings (estimated at 100 sq. ft. per man-hour). 1,000,000 ÷ 100 = 10,000 man-hours.

Total man-hours 16,000

Organization chart (table XVI) 24 men per crew.
Assumed working strength of one company = 120 men.
120 ÷ 24 = 5 available crews per lettered company.
With all five crews working, 120 man-hours per working hour are available.
Based on a 10-hour working day, the available man-hours per company per day are:
120 x 10 = 1,200 man-hours per day.
Laying time in days:
Runway: 6,000 man-hours ÷ 1,200 = 5.0 days of 10 hours each.
Taxiways and hard standings:
10,000 ÷ 1,200 = 8.3 days of 10 hours each
Total = 13.3 days of 10 hours each.

j. Temperature changes. During laying operations provision should be made to offset possible difficulties arising from expansion or contraction of the metal. Mats laid with the expectancy of a 50° to 100° rise in temperature should be pulled as far apart as connecting devices will allow. Conversely, mats laid with the expectancy of a large temperature drop should be laid as close together as connection devices permit.

140. MAINTENANCE AND REPAIR. a. General. Continuous inspection and proper preventive maintenance will reduce materially damage to steel mat surfaces. Inspection should be made on regular schedule and defects in base or drainage and damage to mat panels or connections should be remedied immediately. Neglect of the mat may result in serious damage to aircraft using it.

Figure 102. Steel landing mat damaged by bomb hit.

b. Replacements. (1) Extra panels and connecting-device materials should be kept on hand at all times for quick repairs. The quantities of replacement parts should be increased materially if bomb damage (fig. 102) or strafing is anticipated. All steel mats are designed to allow quick removal and replacement of individual panels.

(2) Pierced type panels can be replaced by removing clips with a pick, slightly lifting the end opposite the direction of bayonet hooks, and sliding the panel back to disengage the hooks.

(3) Bar-and-rod and Irving-grid panels are removed by bending back the wings of connectors, sliding the slip rings free, and lifting out the mat.

(4) The Sommerfeld type individual roll can be taken out by removing the bars. New rolls are inserted by relieving the tension on adjacent rolls and inserting new threading bars. The tension can be relieved by applying pinch bars on each side of the gap, taking care not to damage or bend the threading bars. If bars or rods are bent but not severed, they can be straightened readily by the tool provided and a 7-pound hammer.

c. Repairing base. (1) Low, soft places which develop should be drained and filled. To make a fill the mat is removed, select material is placed in the depression and tamped, and the panels replaced. Slight depressions can be improved by scattering selected material on the panels, raising the mat with an improvised lifting device, and compacting the added material under the panels.

(2) Where pierced plank has been laid on an inadequate base or where dust palliatives are to be applied and use of the runway makes all-over relaying impracticable, the base can be improved by working on sections between flying operations. A joint is disconnected across the width of the runway. Men line up along the freed edge, roll up the mat, and expose the area to be worked on (fig. 103). When the necessary dust palliative or grading and stabilizing operations are completed the mat is unrolled into position, the edges are rejoined, and the runway is ready for operation. Bar-and-rod and Irving-grid sections must be removed completely from areas to be reworked, and relaid upon completion of base repairs.

d. Relaying. Under abnormal conditions of soil, hard usage, extreme temperature change, or poor initial laying, the mat may need to be relaid. This work should proceed rapidly in reverse of the laying operation. As mat sections are removed they should be stock piled similarly to the plan for initial laying. Care is necessary to prevent damage to connecting devices, or loss of parts. Damaged panels should be repaired before being placed in stock piles.

e. Panel repair. (1) Because a panel of pierced plank is reinforced by corrugations, it is difficult to straighten bent panels by hand (fig. 88). A portable machine is being developed to straighten these panels, and will be issued to all air forces. The machine can restore panels to their original condition, except that badly damaged bayonet hooks are cut off with a torch and are not replaced. A cleaning and painting unit is included. After rehabilitation,

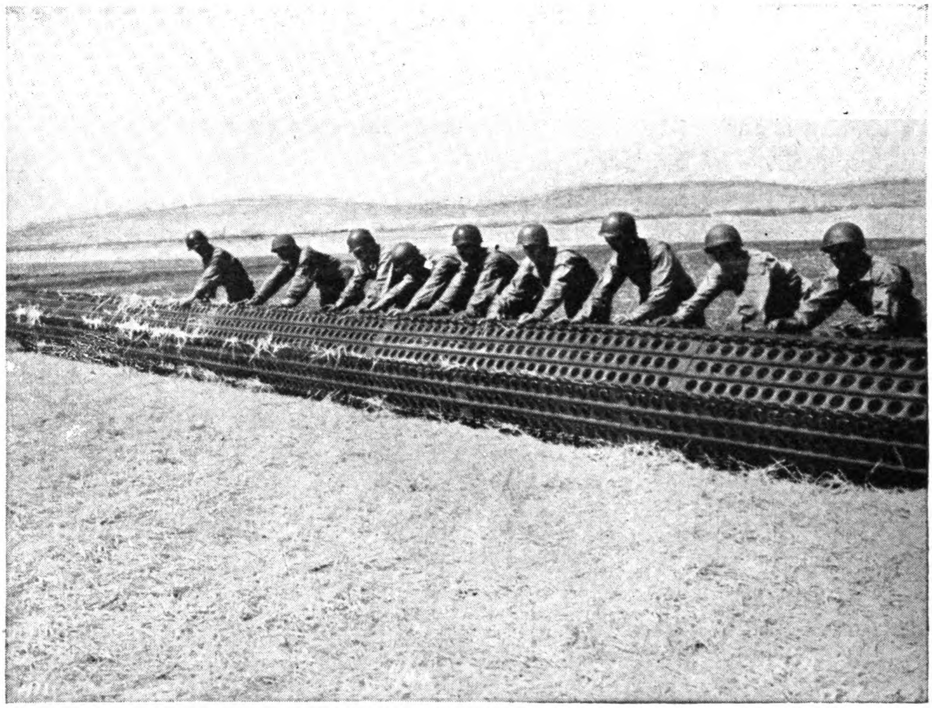


Figure 103. Pierced plank rolled up to expose base. Note straw mulch dust palliative. (See par. 143.)

panels may be bundled for reuse. In cases where damage is severe, as, for example, after bombing or strafing, damaged panels may be cut into 5-foot lengths. The good pieces then are used to fill in at the ends of rows (fig. 104) and the others are discarded.

(2) Irving-grid and bar-and-rod mats are rigid. To straighten bent panels each must be handled separately. It is turned over, laid on firm ground, and pressed back into shape by running a truck or roller over it.

(3) The tension required to lay Sommerfeld mat properly automatically flattens out most kinks. Some hand work may be required on badly deformed areas.

(4) Heating mat sections at points of deformation will assist in straightening operations.

f. Blisters. The mat seldom will creep or expand sufficiently to form blisters. If they occur, usually they can be removed by taking up the panels and relaying with slight adjustment to the connections.

g. Reference. See chapter 24 for general information regarding maintenance.

141. CAMOUFLAGE. **a.** During the construction and maintenance of airdromes using steel runway surfaces the general principles of camouflage should be observed.

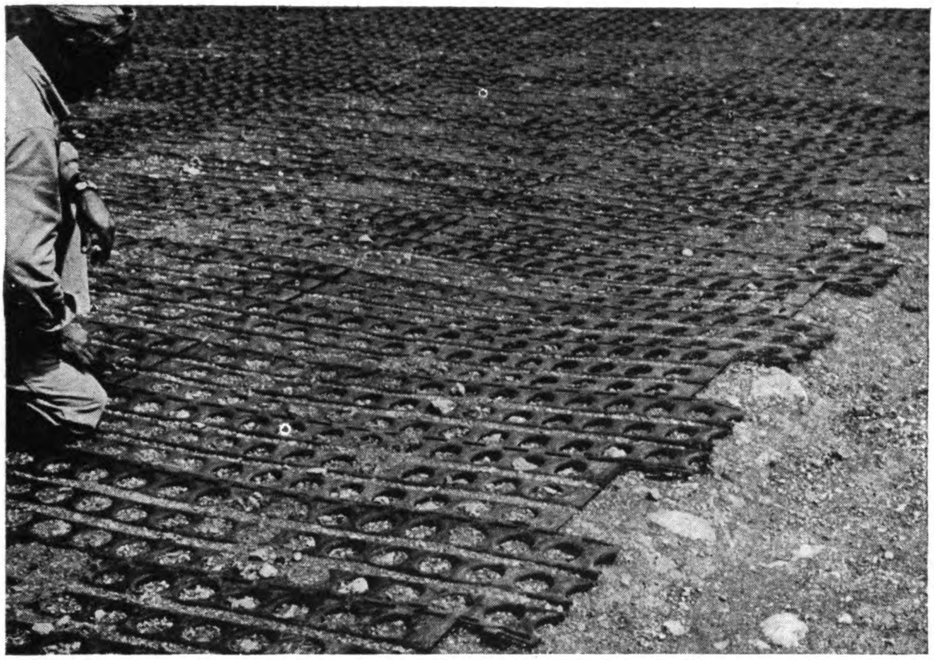


Figure 104. Runway edge finished with cut panels.

b. The difficulty of attaining an effective measure of runway camouflage depends to a large degree on the type of surfacing. The large area covered by a runway makes coloring, toning down, and texturing difficult. An open-type landing mat which permits grass to grow through (fig. 105), thus con-

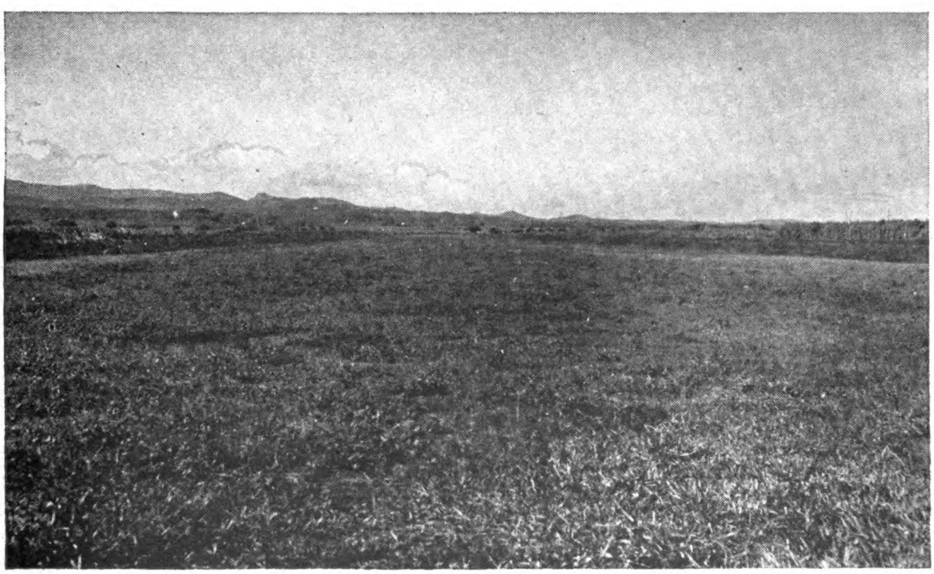


Figure 105. Steel landing mat concealed by growth of native grass.

cealing itself, affords good runway camouflage. Mats with the least metal exposed to view are the easiest to conceal and have the least tendency to kill the grass.

c. By dispersing airplanes sufficiently, designing facilities intelligently, covering the exposed areas with grass (par. 203), and avoiding all signs of abnormal activity, an airdrome with steel runways can be made extremely inconspicuous.

CHAPTER 17

DUST PALLIATIVES

142. USE OF PALLIATIVES. a. General. Runways, taxiways, hard standings, and alert aprons are subject to heavy propeller and exhaust blast from airplanes. If not protected by pavements or surface treatments, these areas may become badly eroded and during dry weather are a constant source of dust (fig. 106). Scarred areas adjacent to those used for aircraft operation may also be sources of dust. *Dust is extremely detrimental to airplane motors and in sufficient density creates a hazard to operations by reducing visibility (fig. 107).* Treatments or processes used to control dust are called palliatives.

b. Description of types. Water is the most common dust palliative. To be effective it must be applied periodically. *The time, equipment, and man-power required limit use of this method to temporary installations.* Distribution at night is practical and usually requires less water. Salt water may be used when approved by air forces. Palliatives other than water are of five general types:

(1) Materials laid as a blanket over areas to be protected. Materials used include canvas, burlap, osnaburg, and mulches of oat straw, long-stem native grasses, or foliage which does not become dry or brittle when weathered. Any fabric which is used should be treated with bituminous material as a precaution against moisture rot.

(2) Mulches of straw, grass, and sod strippings *disked into the topsoil.*

(3) Live turf, suitable only when soil and climate are favorable. Scarred or barren areas may be covered with new growth by sowing seed of rapidly developing plants with or without seed of more permanent and wear resistant species. Seed (par. 203) may be sown before or after spreading of a vegetative mulch.

(4) Fluid materials applied to the natural subgrade or base course to bond the surface and prevent displacement of the fine particles from the surface and underlying areas. Materials commonly used include low-vicosity, bituminous materials (table VII), bunker fuel oil, and crude petroleum.

(5) Chemical salts having an affinity for water, such as calcium chloride. This type treatment is ineffective in climates of low humidity. Because of its possible corrosive effect on airplanes calcium chloride should be used only with air forces approval.

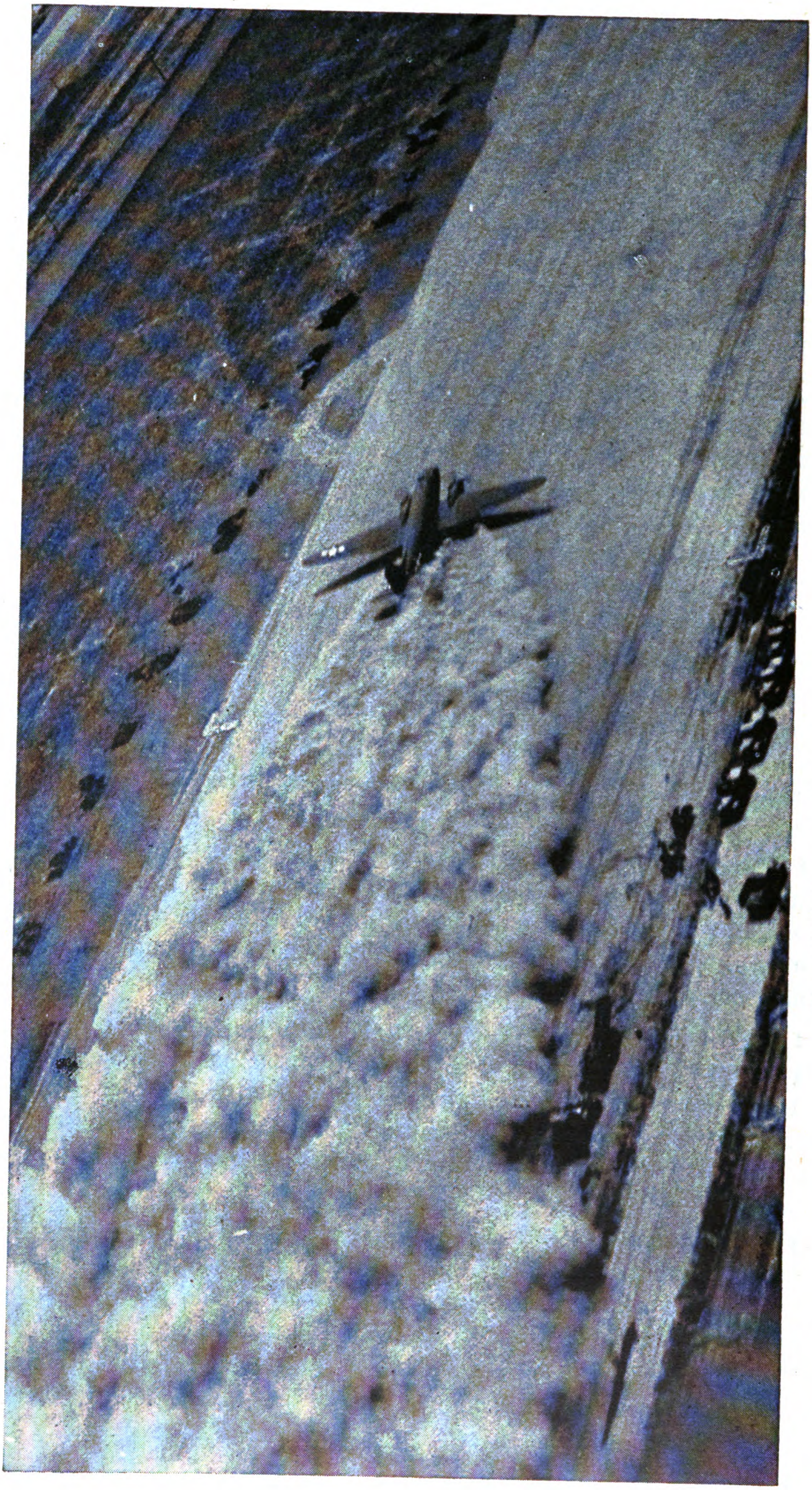


Figure 106. Loose surfaces are a constant source of dust.

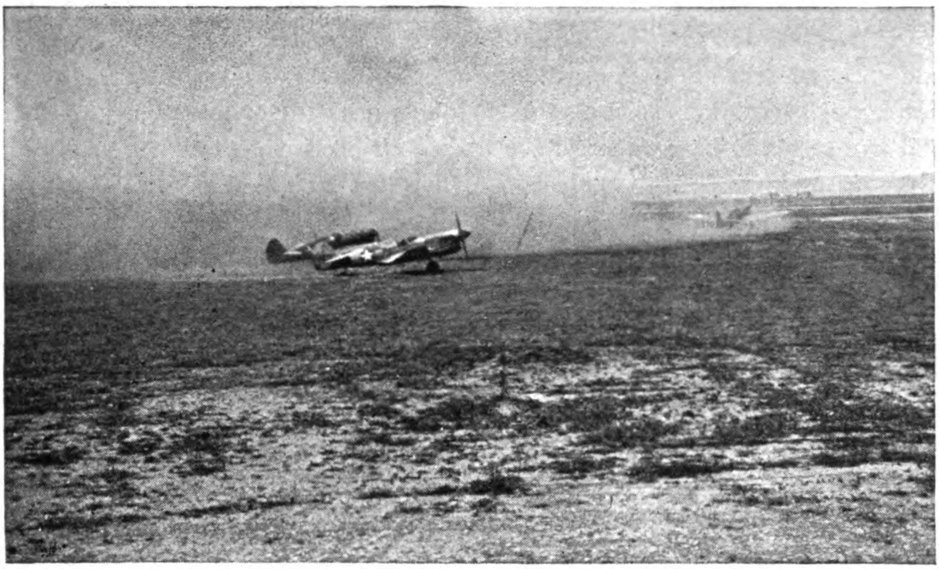


Figure 107. Dust reduces visibility of pilots.

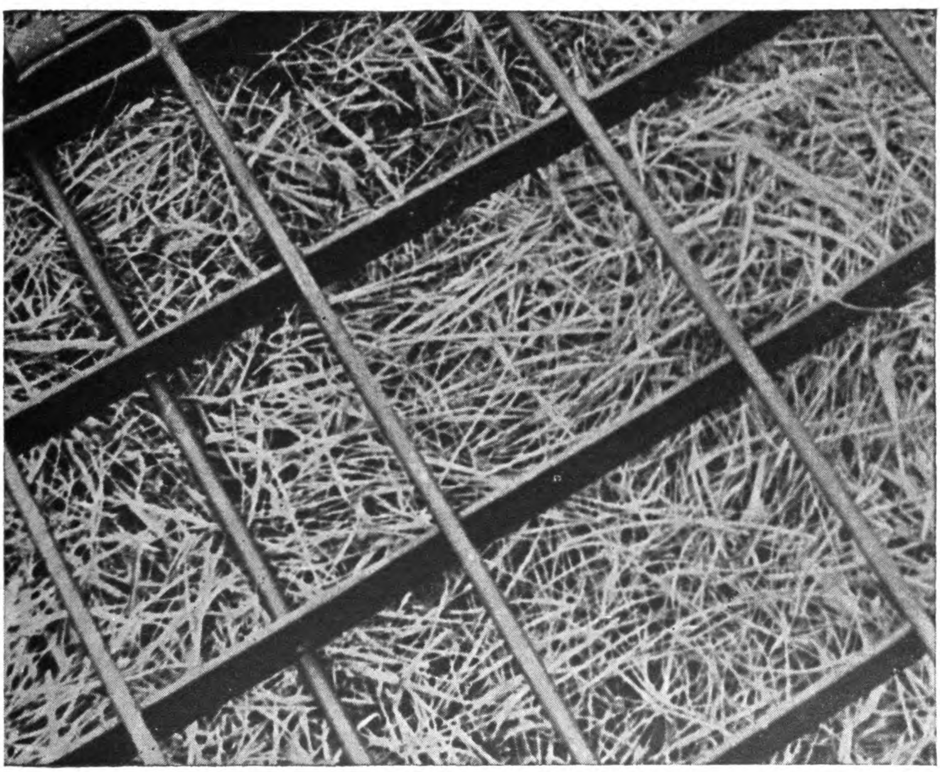


Figure 108. Oat straw used as a palliative under steel landing mat.

c. Selection of treatment. (1) It should be emphasized that unless palliatives are used under steel landing mats, only water, other fluid materials, and chemical salts are used on the runways and other aircraft operating areas. Blanket palliatives are used under steel landing mats only, while disked mulches and live turf may be used under the mat or on areas which are not stabilized. Common areas for disked mulches and live turf include back slopes of cuts, fill slopes and unsodded ground.

(2) Available material, probable use of the area, and the type of soil or base to be treated determine the best method. Rainfall, temperature, and other climatic factors control the selection of turf or other vegetable cover. Mulching material often is locally available and should be used where practicable to save importation of other materials. Blanket palliative materials may be used over any type of soil with uniformly good results. Oat straws and grasses require more maintenance than other palliatives of the blanket type. As quickly as an open spot in the blanket occurs it must be corrected to prevent accelerated damage.

(3) Bituminous material, bunker fuel oil, or crude petroleum is used either as a direct surface penetration or as part of a light mixed-in-place mat. Coarse-grained granular soils (table V) are adaptable to direct penetration while fine-grained soils usually respond better when mixed with the palliative fluids.

143. CONSTRUCTION METHODS. a. General. Suitable native vegetation on the site should be preserved for both dust control and camouflage. Areas to be treated should be graded before palliatives are applied, but should be left with a loose, roughened surface when a disked mulch is to be used.

b. Blanket palliatives. (1) Fabrics are unrolled in lengthwise strips with an overlap of about 4 inches and are tacked down with a 4- by 7-inch wire staple made from No. 9 wire. The legs of the staple are driven through the lapped fabric into the soil. After being placed fabrics should be treated with bituminous fluids. A rate of 0.5 gallons per square yard may be assumed for trial application and adjusted to suit job conditions.

(2) Blanket mulches of straw, grasses, or foliage should be sufficiently thick so no open spaces exist in the mulch when compressed. Approximately 1½ pounds of straw per square yard usually is required. When steel mats are placed over the area care is required to avoid displacement of the mulch.

c. Disked mulches. Disked mulches are evenly spread and anchored to the soil by running over the material with a disk harrow with blades set parallel to the line of travel of the towing tractor. The disks should cut no more than is required to anchor the mulch.

d. Live turf. Seeding and mulching of scarred areas should be undertaken as quickly as possible to provide natural ground cover and to prevent dust. Seed or sprigs of native grasses should be used where available. However, they may be supplemented or replaced by adaptable imported seed of a type which will germinate rapidly, as will rye grass, Sudan grass, millet, and cereal rye.

Seed are sown on lightly scarified soil; a chain, brush, or wire drag is used to cover them. Bermuda grass or similar spreading grasses of local origin are propagated by tearing the sod apart, spreading it over areas to be treated, and disking sod sprigs into the soil to a depth of 2 to 4 inches. In dry soil sprigs are planted in furrows.

e. Liquid palliatives. (1) Where a direct penetration is to be applied, the area to be treated should be wetted and rolled to obtain as compact a surface as possible. When the area is surface-dry, the palliative is applied by pressure distributor. Total amounts applied vary between 0.2 and 0.5 gallons per square yard depending upon the absorption of the material. If the surface is not tightly bonded after curing for 24 hours, additional fluid should be applied. No more liquid is applied than can be absorbed readily by the area being treated. Flooding the surface is avoided. Liquid asphalts or road tars should be applied hot to increase absorption and penetration. Any of the bituminous materials listed as prime coats in table VIII may be used. Experience indicates that penetration of areas underlying steel mats should be undertaken after the mats are in place with the exception that bases should be treated previous to laying pierced-plank mat.

(2) Where fine-grained soils (table V) are to be mixed in place the base is not wetted and rolled. Liquid palliative is distributed as described above and then is mixed into the loose base material by motor graders or brush drags (fig. 111). The total amount of liquid and the number of applications vary with the material being treated. Application of fluid should stop when the mixed material will compress into a ball when grasped in the hand. Mixing continues until the materials are uniform in color and the fluid is completely dispersed. Upon completion of mixing the material is spread to a uniform thickness and compacted with flat-wheel rollers, rubber-tired rollers, or trucks.

f. Chemical salts. Chemical salts are less satisfactory than either liquid or blanket type palliatives. Intermittent rain storms reduce the amount of salts present and make retreatment necessary. Calcium chloride usually is dissolved in water before being applied, good results being obtained with ½ pound per gallon of water. The solution is spread by distributor.

g. Other materials. Mixtures of molasses and water, lignin solution, and other materials of local occurrence may be used within the limits of their effectiveness.

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CHAPTER 18

BITUMINOUS SURFACE TREATMENTS

144. DESCRIPTION AND PURPOSE. Surface treatments are applications of bituminous materials to any type of base or pavement surface, with or without a cover of aggregate, which produce a thickness of less than 1 inch. Their principal purposes are: to waterproof the surface of the base so rain or snow water will not penetrate and increase the moisture content of the base and subgrade to a point where they lose stability; to prevent abrasion and raveling of the base course by the traction of airplane wheels and by propeller blast; and to prevent disintegration and dusting of the base course under traffic in dry weather.

145. TYPES AND LIMITATIONS. a. The four types of bituminous surface treatments suitable for runways, taxiways, hard standings, and roads at airdromes are listed in table XVII. Type I is the simplest and is suitable for light planes and limited service. Types II and III are more waterproof and wear-resistant than type I. On sound bases they are suitable for moderate-intensity use. The choice between types II and III depends upon the size aggregate conveniently available. Type IV is a double surface treatment, capable of fairly heavy service on a sound base.

b. The construction of bituminous surface treatments requires close supervision and control. The quantities of bitumen and aggregate must be adjusted to suit the conditions of each job. Although the construction procedure is simple, for good results a high degree of skill is required of operators.

c. Bituminous surface treatments are justified only if applied to sound, strong bases. Otherwise a dust palliative (ch. 17) should be used. A bituminous surface treatment does not provide the same strength and resistance to hard service as a bituminous pavement, described in chapter 19, but as a step in stage construction it may be used until a bituminous pavement can be constructed. Bituminous surface treatments should not be constructed in wet or freezing weather because under such conditions the bitumen fails to stick to the base and does not bind the cover aggregate. All surface treatments require maintenance and provision must be made at the time of construction to have bituminous maintenance equipment and materials continuously available (ch. 24).

Table XVII. Quantities in gallons of bitumen and pounds of aggregate per square yard for bituminous surface treatments.

Type	Sequence of operations	Prime Coat	Fine aggregate cover (sand)[1]	First bitumen application	Coarse aggregate cover	Second bitumen application	Intermediate-size aggregate cover (coarse sand or screenings)	Approximate surface thickness (inch)
		MC-0, 1, 2 SC-1, 2 RT-2, 3, 4	See figure 34	RC-2, 3, 4 MC-2, 3, 4 AC 120-200 pen. RS-1 RT-6, 7, 8, 9, 10	See figure 34	RC-2, 3, 4 MC-2, 3, 4 MS-1 RT-6, 7, 8, 9, 10 RS-1	See figure 34	
I	Prime coat	0.2-0.5						
	Fine aggregate cover		20-30					1/8-1/4
II	Prime coat	0.2-0.5						
	Fine aggregate cover		20-30					
	Bitumen			0.2-0.3				
	Intermediate-size aggregate cover						20-30	1/4-3/8
III	Prime coat	0.2-0.5						
	Fine aggregate cover		20-30					
	Bitumen			0.3-0.5				
	Coarse-aggregate cover				30-50			1/2-5/8
IV	Prime coat	0.2-0.5						
	Fine aggregate cover		20-30					
	Bitumen (1st application)			0.3-0.4				
	Coarse-aggregate cover				30-40			
	Bitumen (2nd application)					0.15-0.25		
	Intermediate-size aggregate cover						15-25[2]	1/2-3/4

[1] May be reduced or omitted if prime coat is quickly absorbed by the base or if air operations permit sufficient time for prime coat to cure.
[2] This application is brush-dragged before rolling.

146. MATERIALS AND QUANTITIES REQUIRED. Aggregates for bituminous surface treatments are described in paragraph 102. Bituminous materials are listed in table XVII. Quantities per square yard of treated surface are given in table XVII. Except for prime coats the average ratio per square yard of cover aggregate to bituminous binder is 10 pounds of aggregate to 0.1 gallon of bitumen.

147. EQUIPMENT. The organic equipment of the engineer aviation battalion is designed for the construction of bituminous surface treatments. The principal items are the bituminous distributor (fig. 206) and the 1,500-gallon tank (fig. 229). Other equipment such as motor graders and rollers are assigned as needed. Brush or improvised drags (figs. 111 and 112) may supplement the regular equipment. If available, spreader boxes (fig. 110) are desirable for spreading cover aggregate from trucks. For estimating rates of work of equipment see table XXVIII.

148. CONSTRUCTION OPERATIONS. a. Base preparation. The surface of the base is shaped to a proper crown by motor grader and the loose material is consolidated by rubber-tired and flat-wheel rollers while being sprinkled as required. All weak spots observed during base preparation are repaired. Before applying the prime coat the base must be surface-dry and free of caked mud or loose dust. Dust is removed by brooming with the rotary sweeper (fig. 228). Bone-dry bases sometimes are not readily penetrated by bituminous material and may require light sprinkling with water before priming.

b. Prime coat. The bituminous prime coat is applied in one application by a pressure distributor (figs. 109 and 206). The rate of application per square yard is adjusted in accordance with the ability of the base to absorb the prime. This is influenced by the surface porosity of the base, prevailing atmospheric temperatures, and the temperature and grade of the bitumen (table VII). The prime coat penetrates best when the surface of the base is warm. Traffic should be excluded from the prime coat until it is cured. Ordinarily it should be dry enough after 24 hours so it does not stick to tires and pick up under traffic. Where quicker use is required the prime is covered immediately with a blotter course of sand. Excess sand is swept off after curing and before any additional construction is undertaken.

c. Spreading bitumen and aggregate cover. Each application of bituminous material is spread uniformly by the pressure distributor at the prescribed temperature and rate per square yard (fig. 109). The aggregate cover is spread uniformly immediately following the distributor. Aggregates must be clean and free from dust. Better results are obtained if they are dry. Aggregate always is spread ahead of truck wheels. This requires trucks to move in reverse while spreading, whether a spreader attachment or hand-spreading from trucks is employed (fig. 110). Under no circumstances is

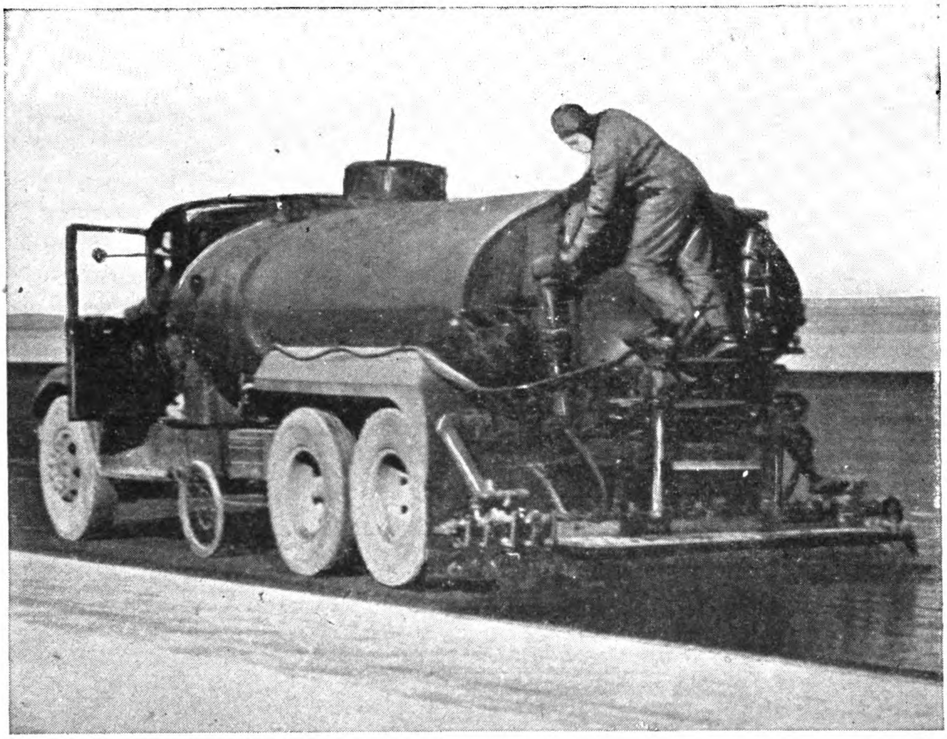

Figure 109. Truck-mounted distributor spreading bituminous material. Note bitumeter wheel.

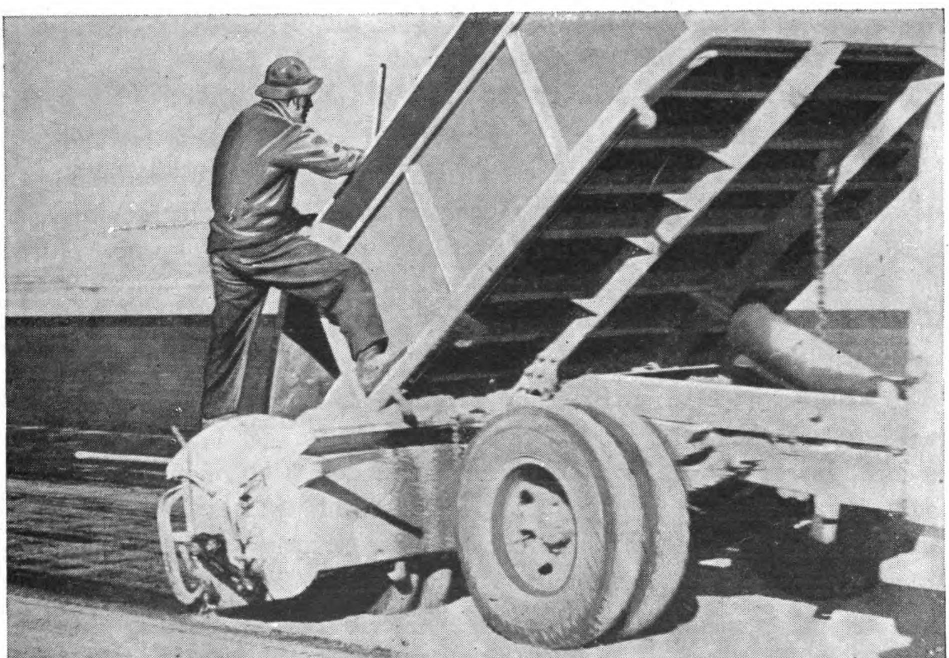

Figure 110. Spreading mineral aggregate over fresh bitumen using spreader attachment. Truck moves in reverse while spreading.

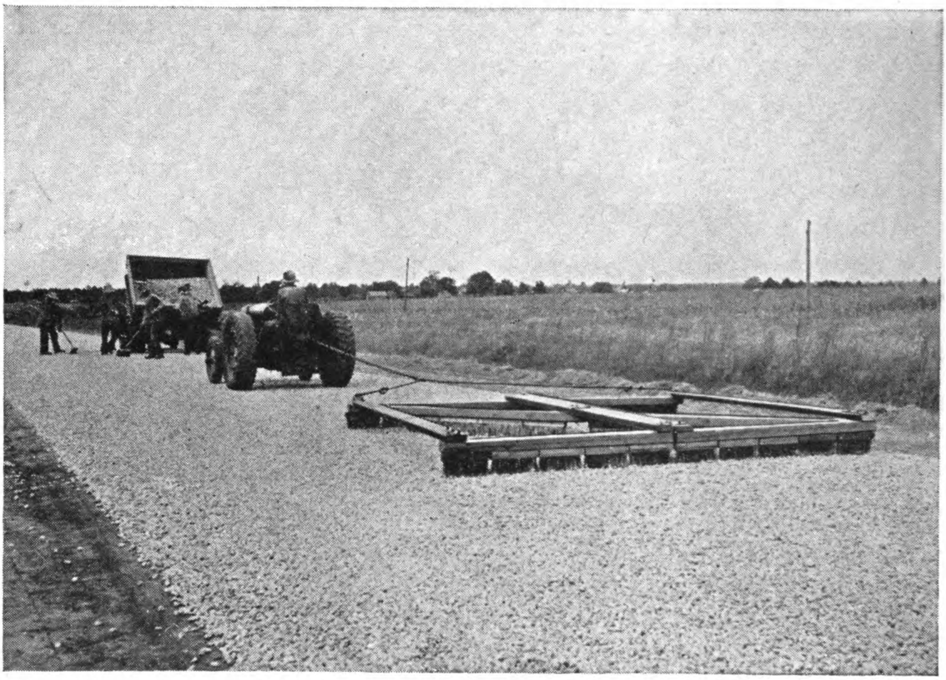

Figure 111. Brush drag.

traffic permitted over uncovered fresh spreads of bitumen. At longitudinal joints aggregate is spread only to within 8 inches of the adjoining uncoated strip until bituminous material has been applied to it. The bituminous application must be uniformly covered with aggregate. Bare spots are covered by hand spreading with shovels from trucks. Irregularities of aggregate distribution are smoothed by hand brooming.

d. Compacting surface treatments. Immediately after speading the cover aggregate is rolled with the two-axle tandem roller. Over-rolling or use of a too-heavy roller may cause excessive crushing of aggregate, which is to be avoided. The rubber-tired roller also is effective for this work. After the bituminous binder has set, the surface is broomed with the rotary sweeper to remove loose unbound particles which are swept into piles and removed from the runway into stock piles.

e. Additional applications of bitumen and aggregate (type IV surface treatment). The second application of bitumen is made as described in c above. It is covered immediately with intermediate-sized aggregate which is brush-dragged (fig. 111) to distribute and coat the particles, then rolled as described in d above. After the bitumen has set the finished surface is broomed with the rotary sweeper to remove all loose particles.

f. Applying bitumen by pressure distributor. (1) EQUIPMENT CONTROL. The spread of bituminous material by pressure distributor is controlled by the pump tachometer and the wheel-operated bitumeter on the distributor (fig. 109). For detailed operating instructions see TM 5-519-4

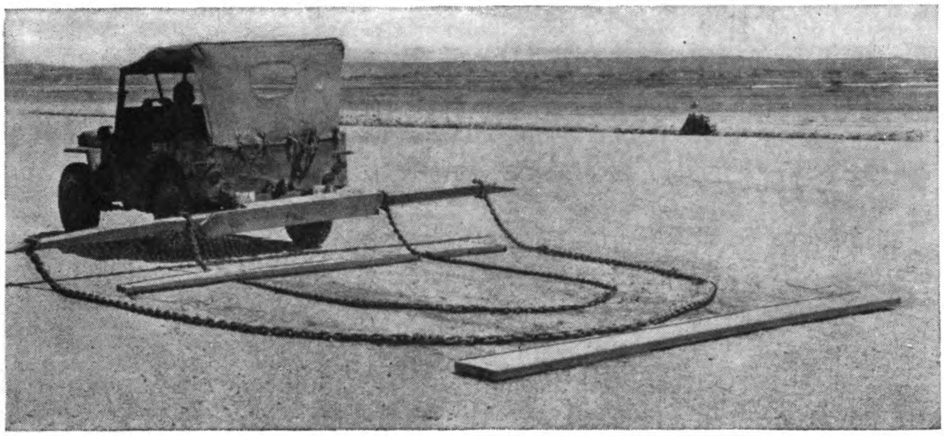

Figure 112. Improvised drag.

or TM 5–519–6. Hand-spraying is employed to touch up all areas missed by the distributor.

(2) TEMPERATURE CONTROL. Practically all bituminous materials are heated for distributor application. They may be heated in storage tanks, in railroad tank cars, in the 1,500-gallon tank trailer with steam coils, or in the distributor itself. Spraying temperatures for spreading are given in table VII. Precautions against fire and explosion must be enforced when heating tar or asphalt cutback. For best results distributor application of bitumen should be made when the air temperature in the shade is above 60°F., and never when it is below 45°F.

149. TECHNICAL CONTROL. Technical control and laboratory assistance during surface construction are vital to good results. Advance information of correct quantities for a particular project can be obtained by constructing test samples on the base course to determine penetration of the prime coat, texture, and final appearance of the surface course.

150. REQUIREMENTS FOR FINISHED SURFACE. All runways, taxiways, and hard standings must be reasonably nonskid and free from loose aggregate particles that may be whipped about by propeller blast. An excess of particles on roads is not harmful.

CHAPTER 19

BITUMINOUS PAVEMENTS

151. DESCRIPTION AND CHARACTERISTICS. a. Bituminous pavements are compacted mixtures of bitumen and aggregate. See chapter 12 for specifications and descriptions of these materials. Depending upon equipment available, character of local aggregate, grade of bitumen available, and weather, bituminous pavements may be constructed by three methods: mixing in place (par. 156); plant mixing (par. 157); and penetration (par. 158). Any required thickness can be built in layers either initially or by stage construction.

b. Bituminous pavements are wear-resistant, waterproof, and flexible. If properly constructed on sound bases, they can accommodate any airplane traffic. They are used instead of a bituminous surface treatment or constructed upon it where air traffic intensity exceeds the capacity of the surface treatment. Being waterproof they protect effectively the base and subgrade from infiltration of surface water. The flexibility of a bituminous pavement permits slight deflections without rupture and eliminates the need for expansion and contraction joints. Unlike rigid pavements (ch. 20) they have no appreciable bending strength to aid in wheel-load distribution by beam action.

c. Bituminous pavements should be constructed upon bases or subgrades that are free from standing water and reasonably dry. They should not be constructed during cold or prolonged wet weather. Temperatures below 45° F. generally require suspension of construction operations.

152. THICKNESS OF PAVEMENT. Minimum permissible thickness of bituminous pavements is shown in table XII. Construction of thicknesses greater than 4 inches is not advisable; thicker bases should be used instead.

153. PROVISION FOR MAINTENANCE. Provision must be made at the time of construction for maintaining bituminous pavements after they are in service. Aggregate for surface patching should be stock-piled, bituminous premix (par. 200e) prepared, and equipment for patching and maintenance provided. (See ch. 24 for methods of maintenance and repair.)

154. TECHNICAL CONTROL. All operations in constructing bituminous pavements require close supervision and technical control. This applies especially to preparation and gradation of aggregates, proportioning aggregate and bitumen, and temperature control. (See par. 14, app. III, for control tests.) Trial mixes or trial sections should be constructed wherever possible to establish the best gradation, proportions, and procedure for each project.

155. ESTIMATING RATE OF CONSTRUCTION. Data in chapter 21 shows rates of work for engineer equipment. The maximum production rates of the main units of equipment, such as aggregate processing plant, mixing plant, and bitumen heater or distributor, are the controlling factors. Operations should be planned and auxiliary equipment provided to utilize the maximum output of the main units.

156. MIXED-IN-PLACE BITUMINOUS PAVEMENTS. a. General. Mixed-in-place bituminous pavements are constructed by mixing bituminous material with aggregate on the runway, road, or taxiway. Usually they are constructed in one layer with a compacted thickness of 1½ to 3 inches. This method is especially applicable where the upper layer of base material is suitable for bituminous construction, and in special cases where the subgrade soil is suitable (par. 128b (2)). Two methods are employed:

(1) Using organic equipment of the battalion, bitumen is spread by the pressure distributor and mixed into the aggregate by a combination of harrow, grader, and rotary tiller; the mixture is spread by a grader and compacted by rubber-tired and flat-wheel rollers.

(2) Using a traveling mixer from class IV equipment in depots (par. 205 and fig. 265), aggregate in windrows is picked up by the traveling plant, bitumen is added and mixed in the plant and the completed mixture is deposited in a windrow behind it, spread by a grader, and compacted by rubber-tired and flat-wheel rollers.

b. Bituminous materials. The grade and type of bituminous material to be used depends upon the character of the aggregate, weather conditions, and equipment available. (See par. 105 and table VIII for recommendations.)

c. Aggregate. Recommended specifications for aggregate are given in paragraph 103. The maximum size of the largest particles of aggregate should not exceed two-thirds the compacted thickness of the layer in which they are used. In general, the aggregate should be well-graded and should contain some dust, other than clay, passing the No. 200 sieve.

d. Proportions. The usual proportion of bitumen to aggregate is shown in figure 35 for each gradation of aggregate. The finer the aggregate the greater the percentage of bitumen. Actual proportions are adjusted by trial on the job. For estimating purposes and as a guide at the start of work, the quantity of bitumen required by well-graded aggregate with a maximum particle size of about 1 inch may be assumed at 0.5 gallon per square yard per inch of compacted thickness, or 0.5 gallon per linear foot of windrowed aggregate per square foot of windrow cross section. (See table LXXII for a method of measuring windrows).

e. Construction procedure. (1) AGGREGATE PREPARATION. (*a*) Where all of the aggregate is obtained from the existing base course, the base first is scarified to the required depth; next, the loosened material is mixed with harrows and graders to break all lumps, and finally it is bladed into parallel windrows of uniform size. Where the uncovered base is loose, a prime coat (par. 148*b*) may be desired. After it has cured the windrows are bladed onto the primed strips and the remaining strips of base are primed. Windrows should have a cross section of 6 to 10 square feet for construction by battalion equipment. If a traveling mixer is used, the cross section may be 10 to 14 square feet. The distance *S* between windrows is the same as the width of runway to be covered by each windrow. It may be estimated by the following equation which is based on a loose windrow volume 1.25 times the compacted volume:

$$S = 10.4 \frac{A}{t}$$

Where: S = spacing in feet of windrows or width of runway to be covered.
A = cross-sectional area in square feet of windrow (table LXXII).
t = compacted thickness in inches of finished pavement.

(*b*) Where it is necessary to blend some material with the existing base material to correct gradation the extra material is hauled in and spread evenly, either before or after scarifying. Where all of the aggregate for the pavement is imported the existing base first is bladed, lightly sprinkled, rolled, primed if necessary, and cured. Then the aggregate is hauled in, dumped in continuous piles, mixed, and bladed into uniform windrows.

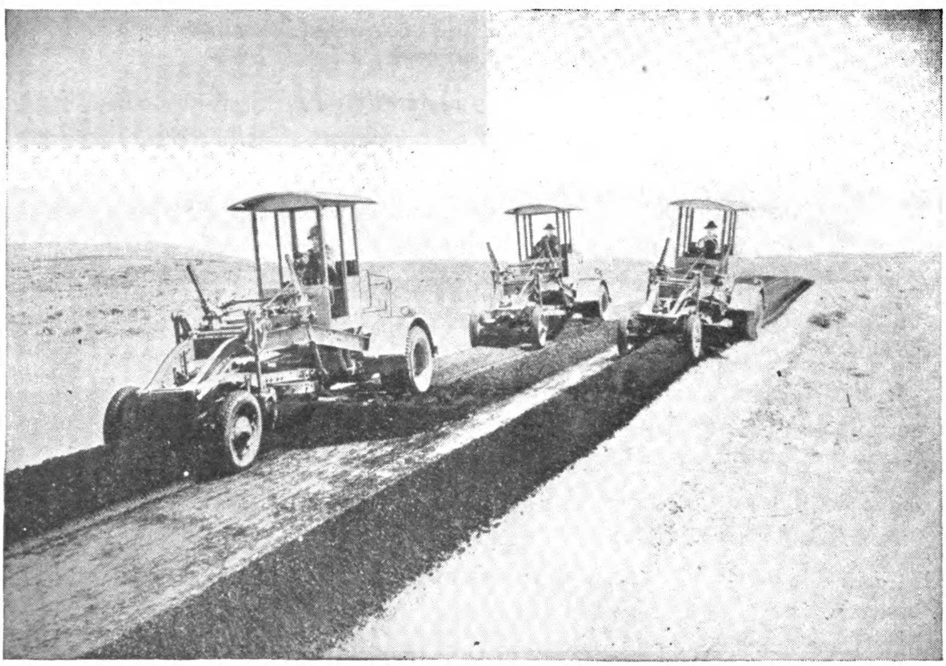

Figure 113. Mixing bituminous material and aggregate with motor graders.

(*c*) The aggregate should be dry before any bitumen, except asphalt emulsion, is added. For coarse-graded aggregate moisture content should not exceed 2 percent and for fine-graded aggregate 4 percent. If the aggregate is too wet, it is necessary to work the windrows by blading to evaporate the excess moisture.

(2) SPREADING BITUMEN. The windrow is flattened and bitumen at the prescribed temperature (table VII) is applied by the pressure distributor (fig. 206) in two or more equal applications until the required quantity has been added. Additional spot applications are made to lean sections during mixing. A harrow follows the distributor after each application to cover the free bitumen and disperse it through the aggregate.

(3) MIXING (figs. 113 and 114). (*a*) The mixing of each windrow is completed by a combination of harrows, graders, and rotary tiller. Where graders are the principal means of mixing, the windrow is moved from side to side by successive cuts with the blade. Several graders operate one behind the other on each windrow. If the mixture becomes wet, mixing continues until it has dried. After mixing is complete the material again is bladed into a windrow preparatory to spreading. If it rains, less water is absorbed by material in a windrow than spread out. All particles of the completed mix should be coated and uniform in color. A desirable mix should "creep" when disturbed. A simple field test is to disturb the windrow slope with the foot and observe the action. If it flows readily, the mix is too dry. If it stands vertically, it is too rich. If it flows or "creeps," it is about right. A handful squeezed in the

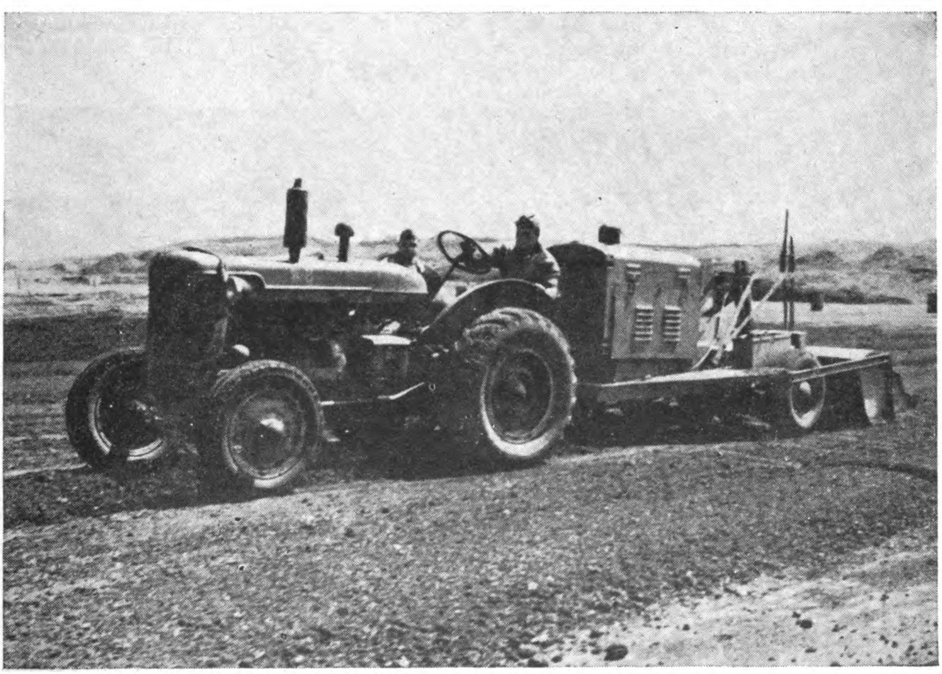

Figure 114. Mixing bituminous material and aggregate with rotary tiller.

palm will compact into a ball and remain in that shape when the hand is opened. A handful rubbed on the palm will leave a brownish stain only when rubbed under pressure.

(*b*) A traveling mixer (fig. 265) accomplishes steps given in (2) and (3) above in one operation. It mixes each windrow progressively by scooping it up in its forward travel, adding and mixing bitumen, and depositing a mixed windrow or a spread mixture behind it. The size of each windrow should be constant throughout its length. If it is not, the amount of bitumen added must be adjusted during travel to keep the proportions of aggregate and bitumen constant.

(*c*) After mixing is completed it may be necessary to work the windrows to aerate them, that is, to permit sufficient cutback solvent and any absorbed moisture to evaporate before the spreading operation and compacting are started. The moisture content of all mixtures, including emulsion mixes, should be less than 2 percent before spreading.

(4) SPREADING THE MIXTURE. Edge stakes should be set to guide the operator and control the width of spread. The mixed windrow is spread by motor grader. The usual procedure is to split the windrow with an angledozer or flatten it with one pass of the grader, then with the grader spread it to each side in increments to uniform thickness and surface slope. Highly skilled operators are needed to do this properly.

(5) COMPACTING. The spread mixture initially is compacted with the two-axle tandem roller, care being taken not to continue rolling if the pavement displaces or "shoves" under the roller. After initial rolling or, if necessary,

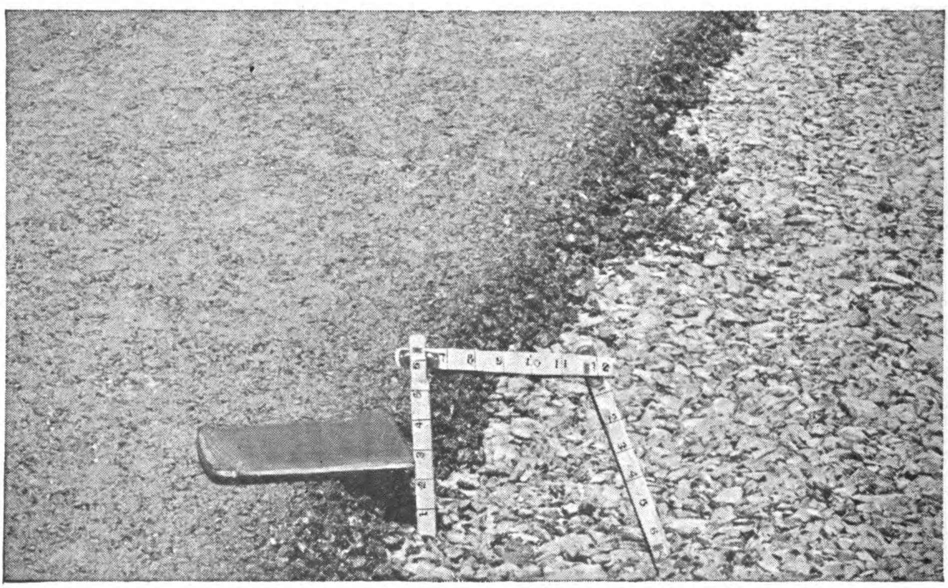

Figure 115. A 2-inch compacted hot-mix pavement on crushed rock base.

elapse of sufficient time for curing so the pavement does not displace, rolling is continued intermittently for several days with flat-wheel and rubber-tired rollers or trucks. Finish rolling is done with flat-wheel rollers, which should commence at the edges of each strip and work toward the center with about 12 inches of overlap on each trip. The steering roll should be to the rear of the roller as it works its way along a strip. Intermittent rolling generally is required because the cutbacks usually used in these mixtures do not harden immediately. The rate at which they harden depends upon weather conditions, the bitumen used, and the degree of aeration during mixing. For these reasons rolling procedure must be regulated to fit job conditions. The pavement can be damaged by premature or excessive rolling.

(6) SEAL COAT. After the pavement has cured and hardened a seal coat with cover aggregate may be applied to insure a watertight pavement and provide a uniform nonskid surface. Bituminous surface treatment type II (table XVII) is recommended, omitting the prime coat and its sand cover.

f. Summary. Table XVIII shows a summary of mixed-in-place operations with materials and quantities.

Table XVIII. Mixed-in-place bituminous pavements, summary of operations, materials, and quantities.

Prime coat*	See paragraph 148b and table XVII.	
Aggregate	See figure 35 for aggregate gradation. Loose thickness of aggregate is about 1.25 times desired compacted thickness. See table XXVIII for estimate of quantities.	
Bituminous material, see table VIII	RC–1, 2, 3, MC–2, 3, 4, MS–1, SS–1, 2, RT–4, 5, 6, 7,	Proportion of bitumen: figure 35. Bitumen is added in increments of 0.3 to 0.5 gallon per square yard with mixing between spreads, except when using traveling mixer.
Mixing	Harrow, grader, rotary tiller; or, traveling mixer.	
Spreading	From windrow in increments.	
Compacting	Rubber-tired roller or trucks and flat-wheel rollers.	
Seal coat	See table XVII, type II bituminous surface treatment: 0.2 to 0.3 gallon bitumen and 20 to 30 pounds of cover aggregate per square yard. Application of seal is delayed to allow pavement to cure.	

* Used only where needed.

157. PLANT-MIXED BITUMINOUS PAVEMENTS. a. General. (1) Plant-mixed pavements are constructed by mixing aggregate and bitumen in a stationary plant set up at some convenient location. The mixed material is transported to the runway, spread, and compacted (fig. 115). The mixing plant consists of portable units which may be assembled in various combinations. It is class IV equipment, available in depots. (See par. 205 and fig. 264 for explanation and description.)

(2) Plant-mixed pavements usually are superior to mixed-in-place pavements because a heavier grade bitumen can be used and there is better control of proportioning and mixing.

(3) The usual thickness of plant-mixed pavements is 1½ to 4 inches. Where the thickness is 3 to 4 inches the pavement is laid in two equal layers, the first layer being the *binder* or *leveling course* and the top layer the *wearing course*. The binder course usually is constructed with a coarser aggregate gradation and with less filler dust passing the No. 200 sieve than the wearing course. If the surface of the binder course becomes coated and dirty because of use before laying the wearing course, a tack coat may be used on it as described in e(2) below.

(4) Plant-mixed pavements are classed as *hot-laid* or *cold-laid* according to the temperature at which they are compacted.

(5) Hot-laid mixtures using asphalt cement and a maximum size aggregate of about 1 inch or larger commonly are called asphaltic concrete. It is the most durable and wear-resisting bituminous pavement. Where the aggregate is graded sand (fig. 35), the pavement is called sand-asphalt pavement.

b. Bituminous materials. See table VIII for recommended bituminous materials. Hot-laid mixes using asphalt cement are recommended wherever equipment and materials permit this type construction.

c. Aggregate. Recommended specifications for aggregate are given in paragraph 103 and figure 35. A variety of graded aggregate can be used but angular particles are preferred, especially for the coarse fraction. Fine aggregates may be crushed particles or natural sand. Dust passing a No. 200 sieve may be rock dust, selected inorganic soil without clay, portland cement, or hydrated lime. Maximum size of the largest particles of aggregate should not exceed two-thirds the compacted thickness of the layer in which they are used.

d. Proportions. The usual proportion of bitumen to aggregate is shown in figure 35 for each gradation of aggregate. Actual proportions are adjusted by trial on the job.

e. Construction operations. (1) BASE PREPARATION. The base for the pavement is bladed, lightly sprinkled, and rolled to correct grade and cross section. Where necessary to tighten the base and promote bond between base and pavement, a prime coat (par. 148b) may be applied. It should be spread sufficiently in advance of paving operations to allow ample curing time. A primed base often can be paved without using a tack coat.

(2) TACK COAT. A tack coat is used only where needed to insure bond between the base and the bituminous pavement, or between the binder and wearing courses. A tack coat differs from a prime coat in that it is not intended to penetrate. The base must be swept clean of all mud and dust with the rotary sweeper. Then the bituminous tack material (table VIII) is applied by pressure distributor at 0.10 to 0.20 gallon per square yard. A cutback used for the tack coat should be applied suffiiciently in advance of paving operations to permit the bitumen to become tacky or sticky before laying the pavement.

It should not be spread so far in advance that it hardens completely or acquires a film of dust.

(3) AGGREGATE PREPARATIONS. Prepared aggregate in two sizes, coarse and fine, is delivered to the mixing-plant hoppers. The reciprocating feeds from the hoppers are adjusted to combine the two sizes so the combination will meet the selected gradation (fig. 35).

(4) PLANT-MIXING — HOT. Where hot plant-mix is used the plant is assembled with the enclosed bucket elevator between driers and mixer (fig. 264). Aggregate is heated in the driers so it reaches the mixer at a temperature of 225° to 350° F. Aggregate must not be overheated. Heated bitumen is added to the aggregate at a controlled rate and mixed in the mixing unit from which the mixture is discharged into trucks for transportation to the job.

Caution: Hot mixing using cutbacks requires extreme care to avoid fires and explosions. Only tanks with inclosed coils should be employed for heating the bitumen.

(5) PLANT-MIXING — COLD. In cold plant-mixing the plant is assembled with an open conveyor belt between driers and mixing unit. The aggregate is heated in the driers to drive off all moisture. The temperature of drying is regulated so after cooling on the conveyor belt the aggregate arrives at the mixing unit at less than 150° F. Heated bitumen is added at a controlled rate and mixed in the mixing unit as in hot plant-mixing. Where asphalt emulsion is employed as the bitumen, heating and drying may be eliminated.

(6) TRANSPORTING MIXTURES. The mixture is transported by truck. Truck bodies should be given a thin coating of Diesel oil to facilitate dumping and prevent sticking.

(7) SPREADING MIXTURES. (*a*) *Hot-laid mixtures.* If a spreading-and-finishing machine (fig. 116) is used, the hot mix is dumped from the truck

Figure 116. Spreading-and-finishing machine laying bituminous pavement. Mixture prepared at mixing plant and delivered to runway by truck.

directly into the spreader. A drag improvised from timber also may be used. Where hand-spreading and raking are used the hot mix should be trucked to dump boards, from which it is spread.

(*b*) *Cold-laid mixtures.* Cold-laid mixture may be spread and finished by a spreading-and-finishing machine (fig. 116), or spread from windrows as described in paragraph 156e. Where this is done the trucks dump the mixture into rough windrows shaped to a uniform cross section by graders before spreading starts.

(8) COMPACTION. Rolling proceeds in a lengthwise direction beginning at the outer edges of each strip and working toward the center, successive trips overlapping by about one-half the width of the rear roller. If the mixture tends to stick to roller wheels they are moistened with water or light oil.

(*a*) *Compacting hot-laid mixtures.* These must be compacted while they are hot. Initial rolling is done with the 10-ton, three-wheel roller. Final rolling consists of lengthwise, diagonal, and cross rolling with a two-axle tandem roller.

(*b*) *Compacting cold-laid mixtures.* These are compacted in the same manner and with the same precautions as mixed-in-place pavements. (See par. 156e (5).)

(9) JOINTS. Lengthwise and transverse joints require special attention to insure a good junction. In hot-laid construction the old work is hand trimmed before new work is started. Hand work is necessary to patch and seal these joints where they are imperfect.

(10) SEAL COAT. See paragraph 156e(6).

f. Summary. Table XIX shows a summary of plant-mix operations.

Table XIX. Plant-mix bituminous pavements, summary of operations, materials, and quantities.

Tack coat (see table VIII).	RT–4, 5, 6, 7, 9 RC–2, 3, 4 RS–1	See paragraph 157e(2). Rate of application 0.10 to 0.20 gal. per sq. yd.
Aggregate	See paragraph 103 and figure 35 for aggregate gradation. See table LXIV for quantities for various thicknesses.	
Bituminous material (see table VIII).	Hot-laid: RC–1, 5; MC–1, 5; SC–5, 6; AC 85–150 pen.; RT–11, 12.	
	Cold-laid: RC–2, 3, 4, 5; MC–2, 3, 4; SC–3, 4; MS–2, 3; SS–1, 2; RT–9, 10, 11.	
	Proportion of bitumen: see figure 35.	
Mixing	Central plant.	Hot-laid mixture, 250 to 350° F.* Cold-laid mixture, less than 150° F.
Placing mixture	Trucks dump to spreading and finishing machine; hand-spread from dump boards; or spread from windrow in increments as in mixed-in-place construction.	
Compaction	Hot-laid mixture: flat-wheel rollers.	
	Cold-laid mixture: rubber-tired and flat-wheel rollers.	

* Temperature should not exceed 300° F. where RC–5, MC–5, and RT–11 and 12 are used.

158. PENETRATION MACADAM PAVEMENT. a. General. (1) This is a pavement constructed of coarse, angular macadam aggregate (par. 101c), spread and compacted on the base, penetrated with bitumen sprayed from a pressure distributor, and covered with smaller aggregate. The finished thickness generally is 2½ inches but may vary from 2½ to 4 inches.

(2) This pavement derives its stability from both the mechanical interlock of the compacted angular aggregate and the cohesion of the bitumen. It is durable and wear-resistant. Its use is advantageous where coarse crushed aggregate is available.

(3) Except for preparing the aggregate, penetration macadam pavements can be constructed with battalion equipment.

b. Bituminous materials. See table VIII for recommended grades.

c. Aggregate. See paragraph 101c for aggregate requirements.

d. Construction operations. (1) BASE PREPARATION. The base for this pavement is bladed, lightly sprinkled, and rolled to correct grade and cross section.

(2) SPREADING AND COMPACTING COARSE AGGREGATE. (*a*) The runway is divided into lengthwise strips, 15 to 30 feet wide. Coarse aggregate without segregation of sizes is spread in a uniformly loose layer guided by stakes, ribbons, or side forms. For a 2½-inch finished pavement the loose spread is about 3½ inches. If spread by hand each load or pile is dumped outside the area upon which it is spread. Suitable precautions are taken to prevent aggregate from becoming mixed or coated with dirt or other objectionable matter before and after spreading.

(*b*) Coarse aggregate is dry-rolled with a 10-ton three-wheel roller (fig. 117). Rolling proceeds lengthwise, starting at the sides and proceeding toward the center, overlapping on successive trips by at least one-half the width of the rear wheel. The compacted coarse aggregate is tested with a 10-foot straightedge to insure a firm, even surface, true to cross section. Any irregularities appearing during or after rolling are remedied by loosening the surface and removing or adding coarse aggregate as required. The area disturbed, including surrounding surface, is rolled until compacted satisfactorily to a uniform surface. All coarse aggregate which becomes coated or mixed with dirt or foreign substances prior to the application of bitumen must be removed and replaced with clean aggregate of the same kind, after which the area is compacted as specified.

(3) FIRST APPLICATION OF BITUMEN. By pressure distributor, bitumen is applied uniformly upon the rolled coarse aggregate at a rate of 1.8 to 2.1 gallons per square yard at application temperature (table VII). Bitumen is applied only when the coarse aggregate is thoroughly dry for its entire depth and when the air temperature is not less than 45° F. in the shade. Where asphalt emulsion is used the aggregate need not be dry and preferably should be slightly damp, but the same temperature limitation applies. Also, because of the fluidity of emulsion, it is desirable to key the coarse aggregate *before*

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Figure 117. Compacting coarse aggregate preparatory to penetration with bituminous material.

applying emulsion to plug some of the surface voids and prevent the emulsion from penetrating too deeply and concentrating in the bottom of the pavement rather than in the top.

(4) FILLING SURFACE VOIDS. Immediately after the bitumen has been applied to the coarse aggregate, clean, dry, fine aggregate (par. 101c) is sprinkled over its surface at 25 to 35 pounds per square yard. Rolling continues, with supplemental adding and sweeping of fine aggregate, until the pavement is bound firmly together, with a hard smooth surface that shows no perceptible movement under the roller. Fine aggregate for this purpose must be ready for immediate use when the bitumen is applied. Aggregate is applied from trucks moving in reverse.

(5) SECOND APPLICATION OF BITUMEN AND FINE AGGREGATE. A second application of bitumen is applied under the same conditions and in the same manner as before, except the rate of application is 0.25 to 0.35 gallons per square yard at application temperature. After the second application of bitumen clean, dry, fine aggregate is spread at the rate of 20 to 30 pounds per square yard, rolled, and broomed until surface voids between coarse aggre-

gate fragments have been filled. Upon completion no loose aggregate should remain on the surface. The finished surface must be uniform, free from porous areas, ruts, or irregularities in contour, and true to established line and grade. (6) BACK ROLLING AND FINISHING. The finished surface is rolled as needed. Total rolling, including dry rolling and back rolling, should average not less than one roller in continuous operation for 1 hour on each 100 square yards, operating at a speed of not more than 3 miles per hour. The surface of the finished pavement must be free from depressions exceeding 3/8 inch as measured with a 10-foot straightedge paralleling the center line of the runway.

e. Summary. Table XX shows a summary of operations for penetration macadam construction.

Table XX. Bituminous penetration macadam pavements, summary of operations, materials, and quantities

Coarse aggregate	See paragraph 101c; loose thickness 3½ inches for a 2½-inch compacted pavement. See table LXIV for quantities.	
First application of bitumen.	RC–5; SC–6; AC 85–150 pen.; RS–1; RT–11, 12	Rate: 1.8 to 2.1 gallons per square yard.
Fine aggregate	See paragraph 101c	Rate: 25 to 35 pounds per square yard.
Second application of bitumen.	Same bitumen as in first application.	Rate: 0.25 to 0.35 gallons per square yard.
Fine aggregate	See paragraph 101c.	Rate: 20 to 35 pounds per square yard.

CHAPTER 20

RIGID PAVEMENTS

159. REFERENCE. For complete information on concrete materials and construction see FM 5–10.

160. DESCRIPTION AND CHARACTERISTICS. a. The common rigid-type pavement for runways is portland cement concrete. It is a high quality pavement capable of the heaviest air traffic if properly designed and constructed. Because of its rigidity and beam action it distributes a wheel load over a greater area of subgrade than does the same thickness of base course of natural material or flexible type pavement. However, unlike flexible pavements, it does not adjust itself to minor settlements or subgrade movements. Minimum thickness of concrete slabs is 6 inches. Above this minimum the required thickness depends upon the subgrade, the flexural strength of the concrete, and the size of plane to be carried.

b. Concrete pavement construction is relatively slow. Under favorable field conditions, using the 14-cubic-foot mixers, working 10 hours per day, it is estimated that in the theater of operations a battalion would require approximately 2 months to construct a concrete runway, 100 by 6,000 feet exclusive of earthwork. About 1 month would be required, using the 34-cubic-foot mixer and accompanying units in the concrete plant included in class IV equipment (par. 205).

c. The use of concrete pavements ordinarily is limited to important airdromes carrying intense traffic, or to special installations of limited extent at field airdromes. Common examples of the latter are aprons, hard standings, and other areas commonly used for turning airplanes.

161. TECHNICAL CONTROL. All operations in concrete construction require close supervision and technical control. This applies especially to preparation and gradation of aggregate, proportioning of the concrete mix, batching, mixing, placing, and curing.

162. DESIGN OF SLAB AND BASE. a. General. A thorough study of subgrade soils and conditions is required. If frost is a factor, particular attention should be given to the frost-action characteristics of the subgrade soils (par. 95).

b. Thickness of concrete slabs. Table XXI shows required thickness of concrete for various design wheel loads and subgrades at locations not subject to frost action. Table XXII shows required thickness and quality of base course and required thickness of concrete for various design wheel loads and subgrades at locations where frost action is a factor. Figure 118 shows recommended cross sections.

Table XXI. Concrete pavement thickness required in areas not subject to frost.

Classification of subgrade soil (see table V).	Group	Design wheel load (pounds) (see table III).		
		15,000	37,000	60,000
		Minimum thickness of concrete (inches)		
GW, GC, GP, GF, SW, SC	A	6	7	9
SP, SF, ML	B	6	8	10
CL, OL, MH, CH, OH	C	6	9	11

NOTES

1. Values in table are based on following assumptions:

a. Subgrade compacted to at least 95 percent of maximum density as determined by modified AASHO test (par. 10, app. III).

b. Concrete breaking strength, 28-day, in flexure (modulus of rupture) of at least 600 pounds per square inch. Concrete of this strength has a 28-day compressive breaking strength of approximately 4,000 pounds per square inch. If flexural strength is 500 pounds per square inch the slab thickness should be increased 1 inch. If flexural strength is more than 700 pounds per square inch the slab thickness may be reduced 1 inch provided it is not reduced below 6 inches.

2. Thickness may be reduced 1 inch for every 6 inches of well-compacted base material composed of GW, GC, or GP soils, or 8 inches of well-compacted SW, SC, or GF (with no excess clay binder) soils, except minimum thickness may not be less than specified for group A. A well-compacted base means compaction to 95 percent of maximum density as determined by modified AASHO test (par. 10, app. III).

c. Joints. Concrete pavements must be provided with expansion, contraction, and construction joints. Figure 118 shows recommended spacing and design.

163. MATERIALS. a. Cement. Standard portland cement generally is used although high-early-strength cement may be used if available (par. 106). The procedure with high-early-strength cement is the same as with standard cement. In 3 days of curing it attains a strength about 75 percent of the strength of standard portland cement at 28 days. High-early-strength concrete may be especially useful in paving the last strips on a runway so its use is not delayed by their curing.

b. Aggregates. Requirements for gradation and quality of aggregate are given in paragraph 104 and figure 36. Maximum size of gravel should be about 2 inches.

Table XXII. Base-course and concrete pavement thickness required in areas subject to frost.[1]

Average depth of frost (inches)	Design wheel load (pounds). (See table III.)					
	15,000		37,000		60,000	
	Minimum thickness (inches)[2]					
	Base	Pavement[3]	Base	Pavement[3]	Base	Pavement[3]
48	6	6	18	7	18	9
36	6	6	12	7	12	9
24 or less, but not less than			6	8	6	10
pavement thickness	6	6	12	7	12	9

[1] Soils subject to frost action are well-graded soils containing more than 3 percent by dry weight of particles less than 0.02-mm in size, and uniformly graded soils containing more than 10 percent of particles less than 0.02-mm in size. (See par. 95.)

[2] The base material must be nonfrost action and compacted to at least 95 percent of maximum density as determined by modified AASHO test (par. 10, app. III).

[3] Values are based on an assumed 28-day concrete breaking strength in flexure (modulus of rupture) of at least 600 pounds per square inch. Concrete of this strength has a 28-day compressive breaking strength of approximately 4,000 pounds per square inch. If flexural strength is 500 pounds per square inch, the slab thickness should be increased 1 inch. If flexural strength is more than 700 pounds per square inch the slab thickness may be reduced 1 inch provided it is not reduced below 6 inches.

Thickness values in tables XXI and XXII refer to *interior thickness,* not edge thickness, of slabs.

c. Water. Water for concrete must be free from oil, acids, alkali, and organic matter. In general, any water fit for human consumption is suitable for concrete. Sea water is not used for concrete in runways.

164. PREPARATION OF AGGREGATES. See chapter 12 for general discussion of aggregate preparation. Concrete pavement aggregate generally is washed and screened into at least two sizes, coarse and fine.

165. CONCRETE-MIX PROPORTIONS. a. Water-cement ratio. The ratio of water to cement in concrete for runways should be not more than 6 gallons of water per bag (94 pounds) of cement. In computing the water content of concrete all moisture carried by the aggregate (and any admixture) is included in applying this rule. In other words, total water including that carried by the aggregate (table LXXVI), by calcium-chloride solution if used, and that added to the mixture, must not exceed 6 gallons per bag.

b. Cement content. Cement content of concrete on runways should be about 5½ bags of cement (517 pounds) per cubic yard of finished concrete. However, this factor may vary from five to six bags per cubic yard, depending upon quality of cement and aggregate available and working conditions.

c. Aggregate. Proportions of fine and coarse aggregate (fig. 36) are adjusted to give a workable, relatively dry plastic mix having a slump (par.

15, app. III) of about 2 inches if to be consolidated by machine. A slump of 3 inches is permissible for hand-tamping and spading. Average proportions of fine and coarse aggregate are 40 percent of fine aggregate (sand) and 60 percent of coarse aggregate (gravel). (See tables LXXIV and LXXV.)

166. ORGANIZATION OF WORK. a. Location of equipment. Figure 119 is a schematic lay-out of runway-paving operations. Equipment for crushing, washing, and screening is placed at the aggregate pit. The batching plant may be located at the processing plant or at an intermediate point between the runway and source of aggregates. Batch trucks carry proportioned coarse and fine aggregate from the batcher to the mixer on the runway. Cement is stored and loaded onto the batch trucks at any convenient site between the aggregate batcher and paver, the exact location depending upon available access and service roads.

b. Schedule of placing. The runway is paved in lengthwise strips from 20 to 25 feet wide, depending upon the width of spreader and finisher available. Paving of the first strip is started at one corner and carried the full length of the runway. An adjoining strip the same width as the first is left unpaved and paving proceeds in the opposite direction on the next strip. Alternate strips are paved in the same manner until the opposite side of the runway is reached. The equipment then goes back to the first unpaved strip and again works across, paving the remaining strips.

c. Balancing equipment. Enough equipment should be provided to maintain an even flow of concrete by keeping the main units of equipment in operation with minimum idle time. Taking the 34E paver as the main unit, for example, other equipment requirements are estimated as explained below.
(1) The 34E paver has an average output of 35 to 40 cubic yards of concrete per hour, or a batch approximately every 2 minutes. Using 40 as a basis, an estimate of cement and aggregate requirements is made as follows. Assuming 2-inch maximum size aggregate, a water-cement ratio of 6, and a slump of 3 inches, the estimated quantities of materials required per hour from table LXXV are—

(*a*) Cement, sacks of 94 pounds each: 40 x 5.70 = 228 sacks per hour.

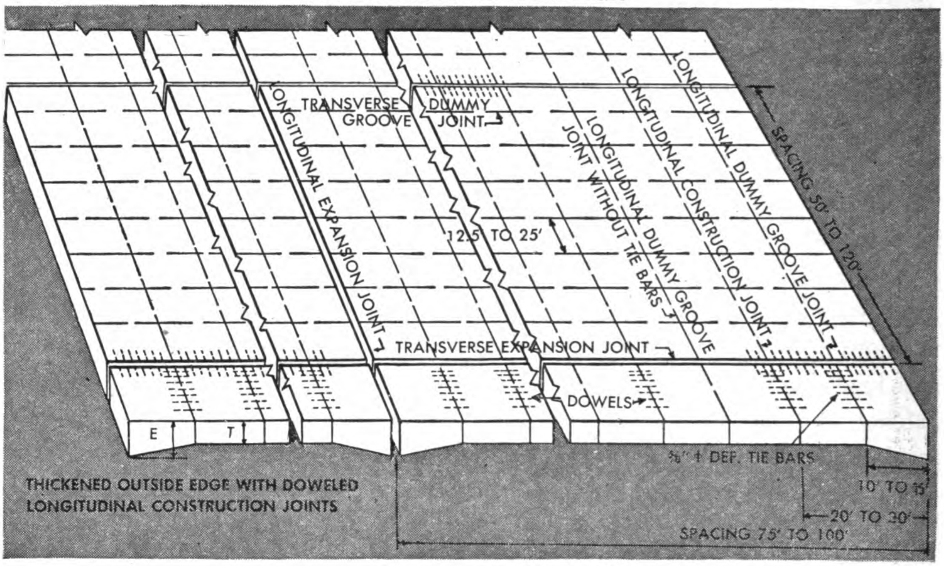
(*b*) Fine aggregate, damp-loose volume: 40 x 0.48 = 19.2 cubic yards per hour.

(*c*) Coarse aggregate, damp-loose volume: 40 x 0.76 = 30.4 cubic yards per hour.

(2) The 34E paver averages one batch of approximately 1¼ cubic yards every 2 minutes, or 30 batches per hour. The volume of the batch is set to use whole sacks of cement. The estimated requirements for one batch from table LXXV are—

(*a*) Cement, sacks of 94 pounds each: 1.25 x 5.70 = 7.1 sacks—adjusted volume of mix to use whole sacks of cement—$\frac{7.0}{5.7}$ = 1.23 cubic yards; 1.23 x 5.70 = 7.0 sacks, or 658 pounds, or 0.32 tons.

TYPE I PAVEMENT DESIGN



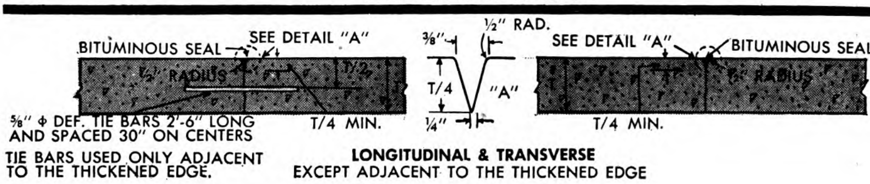
GENERAL NOTES (FOR ALL TYPES)

1. USUAL SPACING LONGITUDINAL EXPANSION JOINTS 75' TO 100' NO LONGITUDINAL EXPANSION JOINT IN WIDTH OF 100' OR LESS.
2. USUAL SPACING TRANSVERSE EXPANSION JOINTS 50' TO 120'.
3. TRANSVERSE CONSTRUCTION JOINTS AS NEEDED, WITH ¾" OR 1" ϕ DOWELS 16" LONG 18" CENTER TO CENTER.
4. TRANSVERSE CONSTRUCTION JOINTS TO BE USED ONLY AT END OF DAYS RUN AND EMERGENCY SUSPENSION OF WORK AND SHOULD BE PLACED AT LOCATION OF CONTRACTION OF EXPANSION JOINTS.
5. LONGITUDINAL CONSTRUCTION JOINTS AS SHOWN.
6. TRANSVERSE DUMMY GROOVE JOINTS SPACED 12.5' TO 25'.
7. LONGITUDINAL DUMMY GROOVE JOINTS MID POINT 20' TO 30'—SLAB WITH TIE BARS ADJACENT TO THICKENED EDGE ONLY.

LONGITUDINAL & TRANSVERSE

CONSTRUCTION JOINTS

EXPANSION JOINTS



LONGITUDINAL & TRANSVERSE
EXCEPT ADJACENT TO THE THICKENED EDGE

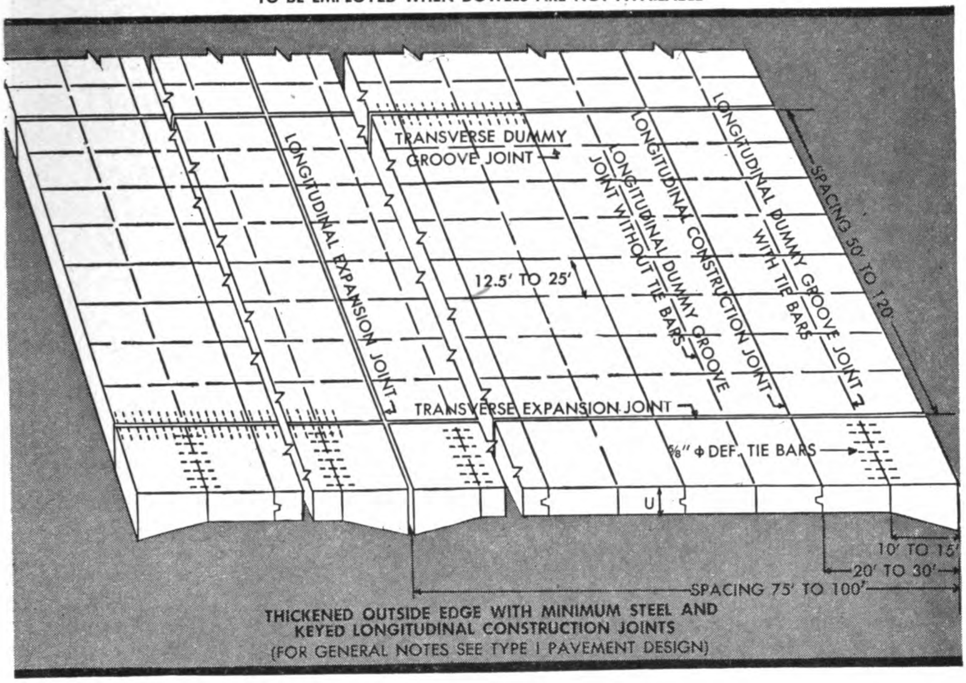
DUMMY GROOVE JOINTS

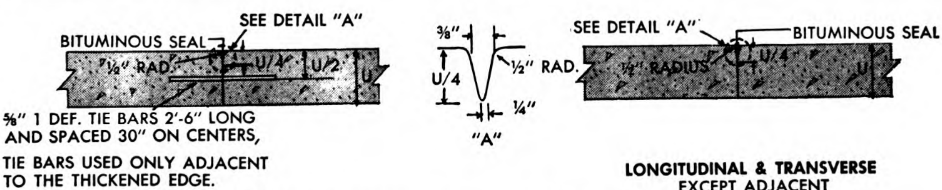
① *Type I.*

Figure 118. Design and spacing of joints and lay-out of concrete slab for runways.

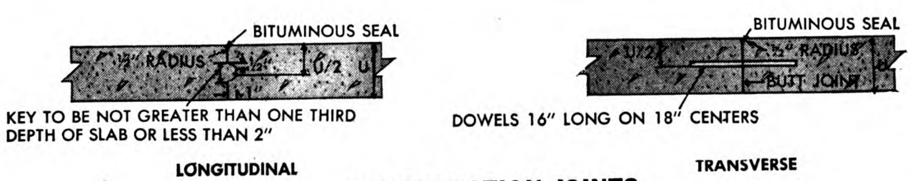
TYPE II PAVEMENT DESIGN

TO BE EMPLOYED WHEN DOWELS ARE NOT AVAILABLE

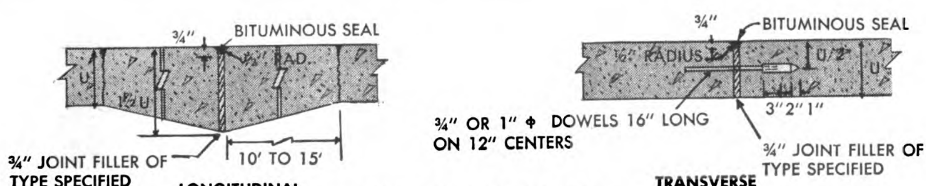




DUMMY GROOVE JOINTS



CONSTRUCTION JOINTS



EXPANSION JOINTS

② *Type II.*

Figure 118. Continued.

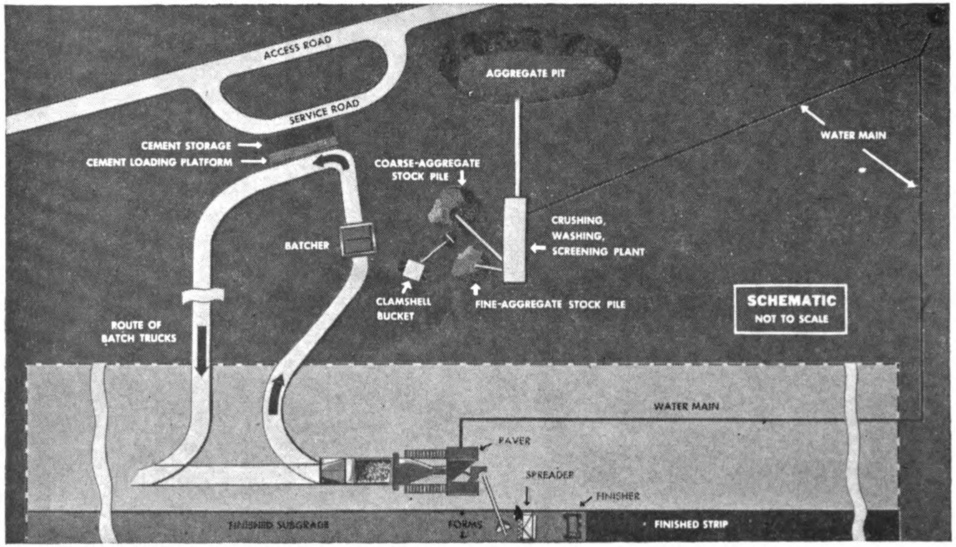


Figure 119. Schematic lay-out of runway-paving operations. (Paver may travel between forms if practicable.)

(*b*) Fine aggregate, damp-loose volume or damp weight: 1.23 x 0.48 = 0.59 cubic yards, or 1.23 x 0.62 = 0.76 tons.

(*c*) Coarse aggregate, damp-loose volume or damp weight: 1.23 x 0.76 = 0.94 cubic yards or 1.23 x 1.04 = 1.28 tons.

(3) The estimated total weight of one batch before mixing is 0.32 + 0.76 + 1.28, or 2.36 tons. Therefore, a 2½-ton dump truck is required for each batch.

(4) For a round trip of 2 to 8 miles trucks will average 5 miles per hour including loading and dumping time. The number of trucks required may be found by the following formula:

$$N = \frac{BD}{bS}$$

in which:

N = Number of batch trucks required.
B = Number of batches per hour mixed by paver.
D = Round-trip distance in miles from paver to batcher
b = Number of batches carried by each truck.
S = Average speed of trucks in miles per hour.

(5) More trucks than shown by the above formula are required for round-trip distances less than 2 miles and fewer for round trips longer than 8 miles. To insure continuous mixer operation a surplus of trucks should be available in case of truck breakdown. Additional trucks are needed to haul cement from the source of supply to the job storage point.

(6) Provision should be made for a surplus supply of cement in storage and aggregate in stock piles to maintain paving operations during temporary shut-downs of the aggregate processing plant or during irregular deliveries of cement and aggregate.

d. Labor requirements. Table XXIII shows personnel requirements for normal paving operations. Noncommissioned officers shown are those used in a supervisory capacity.

167. CONSTRUCTION OPERATIONS. a. Forms. The most common forms for paving are prefabricated steel members (fig. 120). Forms are placed on each side of the strip ahead of the paver and left in place a minimum of 24 hours after the concrete is placed. Forms must be securely set and true to line and grade.

b. Subgrade preparation. Subgrade preparation includes fine grading, compaction by rolling, and sprinkling. This is done just ahead of paving operations. A subgrade template which slides on the side forms is used to test and to control accuracy of operations. If the subgrade is dry, it will absorb moisture from the wet concrete. This is prevented by wetting the subgrade. Light sprinkling just ahead of the concrete is of some value. Thorough wetting the night before is best. On subgrade soils, such as loess, clay, gumbo, adobe, and expansive silts, a covering is desirable to separate the slab from the soil.

Table XXIII. Personnel requirements per shift for concrete-runway paving operations.

Location of job	Men	Noncommissioned Officers	Duties
Gravel pit	Variable[1]	1	Keep steady flow of aggregate material to crusher.
Crushing, washing, and screening plant	9	2	Maintain and operate plant.
Shovel, 2-cubic-yard, clamshell	2	—	Move aggregate from stock piles to batcher.
Batcher	2	1	Load aggregate to batch trucks.
Cement storage and loading	[2]5	1	Add cement to batch trucks. Unload and store cement from cement trucks.
Paver	4	1	Maintain and operate paver.
Spreader	2	—	Maintain and operate spreader.
Finisher	5	1	Maintain and operate finisher. Do any hand finishing required.
Forms (placed on a prepared subgrade—fine grading completed)	[3]20	2	Lay and remove forms. Place dowels at joints. Give final preparation to subgrade.
Water lines[3]	[4]3	[4]1	Maintain water supply.
Curing	7	1	Place cover and keep moist.
Hauling aggregate and cement	Variable[5]	2	Transport cement and aggregate from batcher to paver.

[1] Depends upon size of pit and amount of equipment used.

[2] Depends upon number of trucks used.

[3] Form crew does not do fine grading. This work is done by a special crew of variable numbers depending on the volume of work necessary inside the form area.

[4] For pipe-line supply only.

[5] See paragraph 166.

A subgrade blanket course of sand (par. 126) generally is helpful except on loess, which should have a cover of bitumen-saturated paper.

c. Batching. Aggregates are combined in desired weight proportions at the batching plant (fig. 121). Size of batch is governed by the capacity of the mixer as explained in paragraph 166c. Cement usually is added to the aggregate in the trucks at the cement loading point (fig. 122). However, cement may be added at the aggregate batching plant or at the mixer. Cement should be left in sacks or placed in a separate compartment in the truck to keep it out of contact with wet aggregate until placed in the mixer. Tarpaulins over the truck may be necessary to prevent the cement from blowing away in transit. If trucks are capable of carrying more than one batch, the bodies are subdivided by bulkheads to form compartments for individual batches.

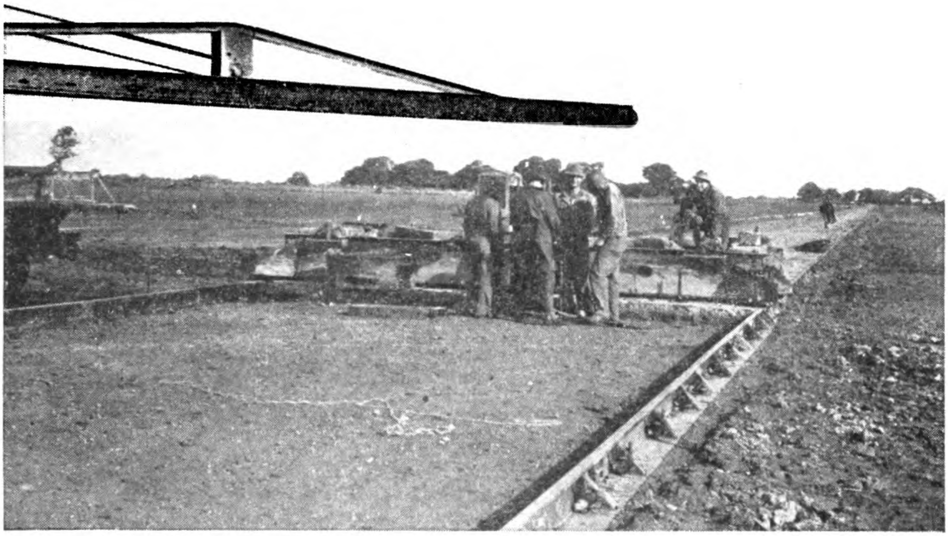


Figure 120. Steel forms in place.

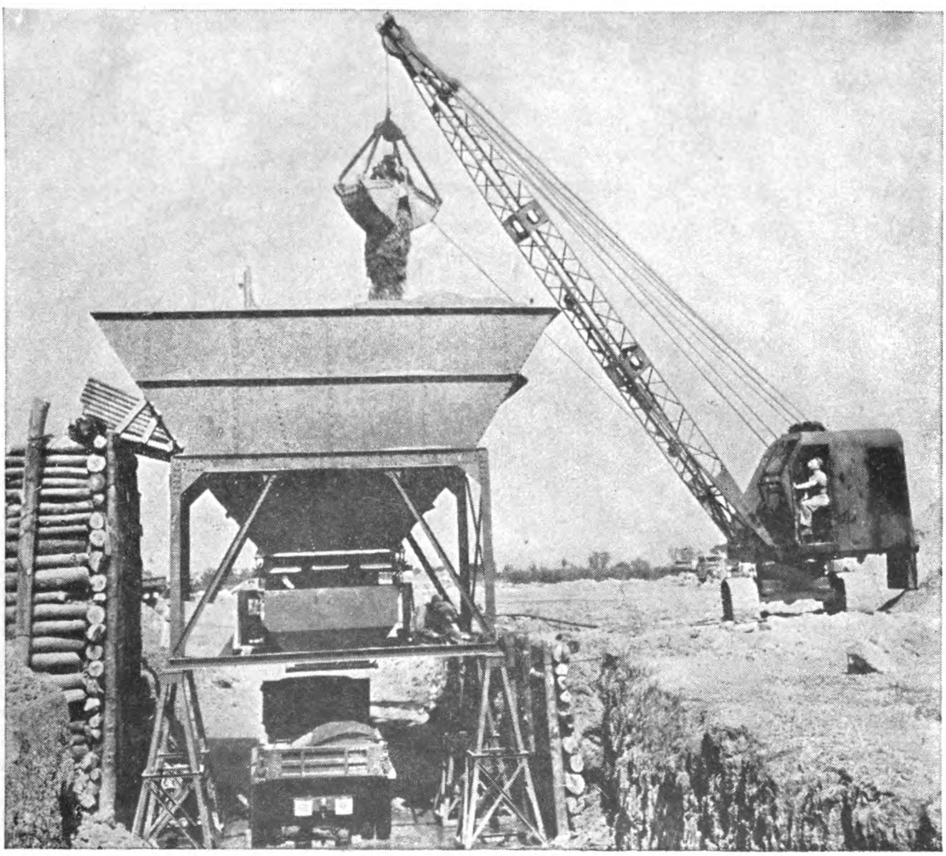


Figure 121. Aggregate batching plant.

Figure 122. Adding cement at cement-loading point.

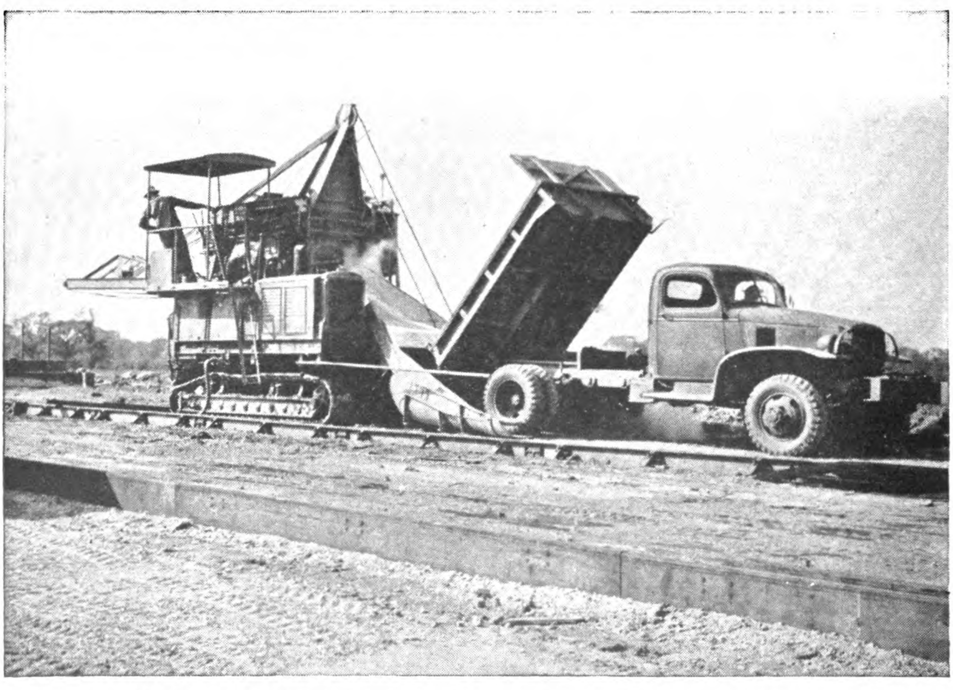


Figure 123. Batch truck dumping aggregate into skip of paver.

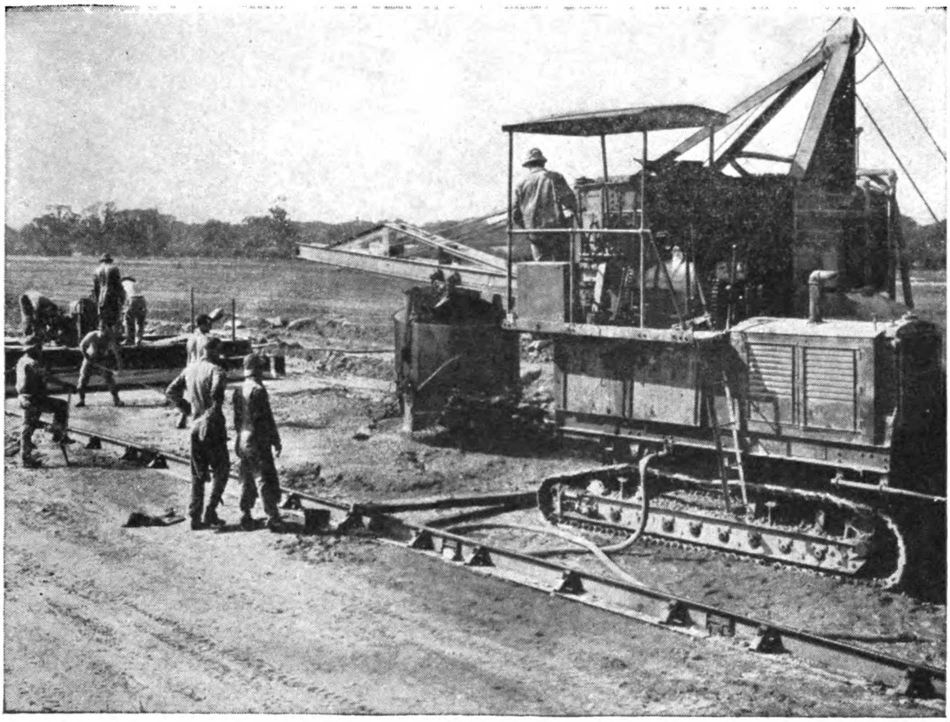


Figure 124. Paver bucket on swinging boom placing concrete.

d. Mixing. Each batch is dumped from the batch truck into the skip on the paver (fig. 123), then elevated into the mixer drum. Water is added from a tank on the paver through a metering device set to control the quantity added. Each batch is mixed at least 1 minute after all materials are in the mixer drum.

e. Placing. After the concrete is mixed it is discharged into a bucket which travels on a swinging boom to the desired place (fig. 124). Joints should be spaced and placed as shown in figure 118.

f. Spreading. The spreading machine (fig. 125) travels on the forms behind the mixer and distributes the concrete across the width of the strip by a moving blade. Behind the traveling blade is a strike-off bar which brings the surface to its approximate final level.

g. Finishing. The finishing machine (fig. 126) rides on the forms in the same way as the spreader. It has a front screed, vibrator, and rear screed. The front screed acts the same as the strike-off bar of the spreader and brings the surface nearer to its final level. The vibrator moves up and down with a simultaneous rocking motion and consolidates the concrete. The rear screed strikes off the final finished surface. Any surface irregularities are smoothed out with hand screeds during the other hand operations, such as edging and trimming joints.

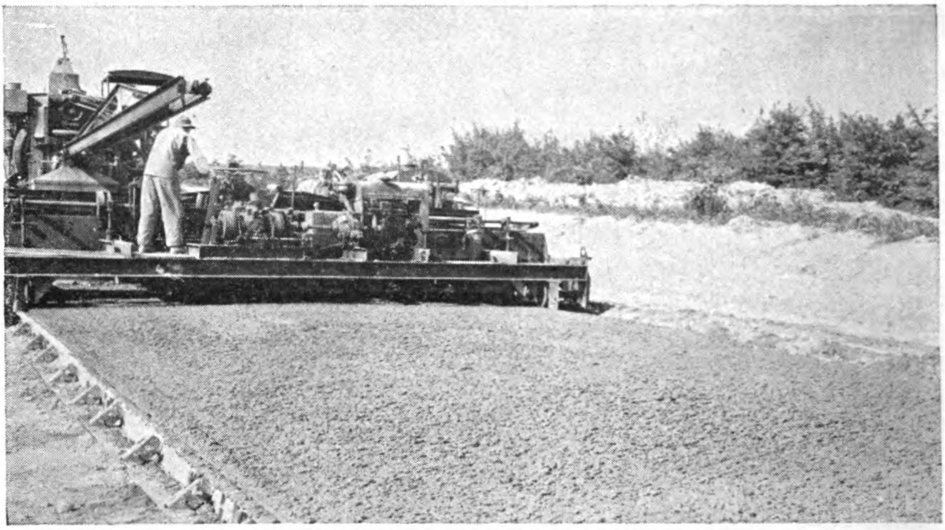


Figure 125. Spreading machine.

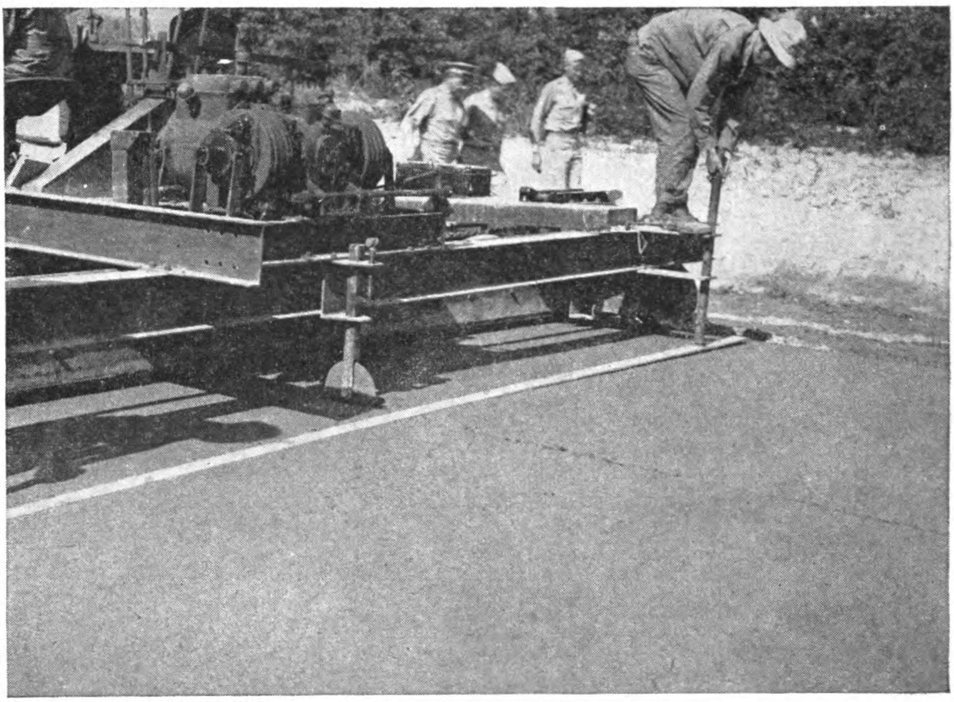


Figure 126. Finishing machine. Note wheel cutting longitudinal dummy groove joint.

h. Curing. (1) Freshly finished concrete slabs must be protected against loss of moisture by evaporation so the chemical reaction between water and cement necessary for development of strength will not be interrupted or retarded. More than enough water is used in mixing concrete to satisfy the

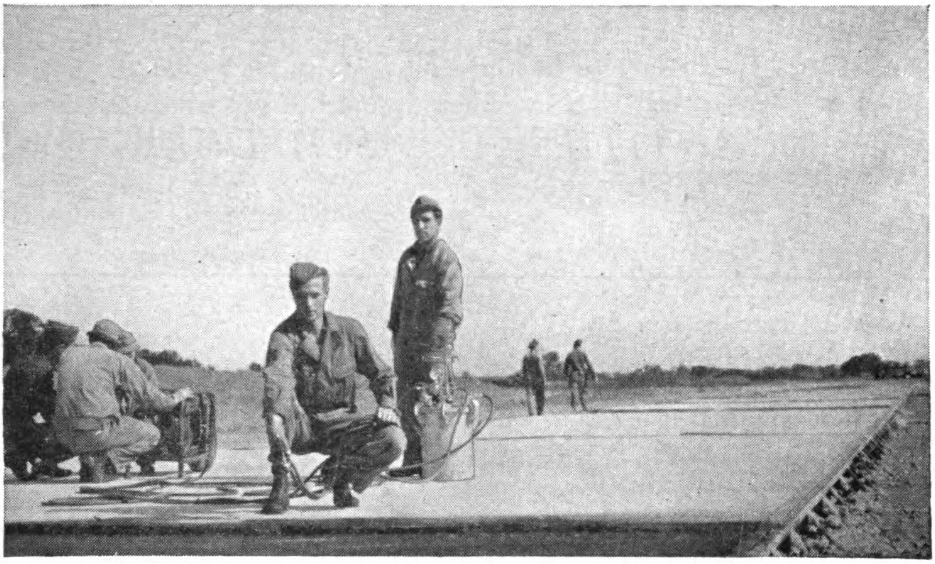


Figure 127. Spraying concrete with curing material.

chemical requirements of the cement. Curing procedure must keep this water in the slab until strength has been attained. Curing should be as thorough as the military situation permits.

(2) As soon as the slab has sufficiently hardened after finishing it is prepared for curing by any standard method: ponding with water; covering with paper; covering with sand or straw kept damp by sprinkling; or covering with a sprayed curing material such as emulsified asphalt, cutback tar, or cutback asphalt (fig. 127). Curing must be continuous. Intermittent sprinkling is not acceptable. The normal curing period for standard portland cement concrete is 7 to 14 days at temperatures above 50° F. and 14 to 21 days if air temperature is below 50° F. The curing period for high-early-strength concrete is 2 to 7 days, depending upon prevailing temperature. Concrete must be protected from freezing during construction and curing.

i. Joint filling. After the concrete is cured the joints are cleaned out and filled with hot bituminous joint filler such as a heavy grade of tar or asphalt.

733495°—47——16

CHAPTER 21

QUANTITIES AND SCHEDULE

168. SCOPE. This chapter explains methods of estimating quantities of material, work, and equipment, and scheduling construction operations, personnel, and equipment for building an airdrome.

169. PRELIMINARY ESTIMATES. a. General. A preliminary estimate is prepared as part of the reconnaissance report (par. 65). This is not a detailed estimate but includes the major construction items such as clearing and grubbing, drainage, earthwork, base courses, and surfaces. Quantities are estimated from aerial photographs or preliminary sketch plans (par. 65), with due consideration of priorities and sequence of construction operations. Estimated quantities may be checked by comparison with construction quantities on similar sites.

b. Procedure. Quantities are estimated for each operation in the proper sequence of the work. Suggested methods of estimation are listed below:

(1) Clearing and grubbing areas are measured on available aerial photographs or estimated from sketch plans. The type and density of clearing are determined from photographs, with ground confirmation. Labor and equipment then are estimated by reference to table XXVIII.

(2) Drainage estimates are based on information obtained from aerial photographs and ground reconnaissance. Lengths of intercepting and outfall ditches and drainage areas are scaled off aerial photographs or sketch plans. Depths of ditches are obtained by measurements on the ground. Cross-sectional areas of drainage structures are determined by the methods described in paragraph 120e(3). Length of structures can be scaled. Excavation for ditches and structures is divided by the productive capacity of the machines to be used (table XXVIII) to determine time required.

(3) Earthwork quantities are estimated from a table of center-line cut and fill volumes, which can be prepared quickly for each site (fig. 128). Minor differences in the transverse ground slope and the typical section slope seriously affect the quantities of cut or fill in 100 feet of landing strip length. This necessitates preparation of a table for each site. The table includes the maximum range of cut and fill for the site. Volumes of cut and fill are tabulated for each 100 feet of length of the landing strip, as shown in figure 57. By scaling from the sketch plans the interval of cut or fill between the

ground profile and the grade line at each station, the quantity of earthwork is obtained directly from the table. Summation of the tabulated quantities gives the total volume to be handled, as illustrated in figure 57.

(*a*) The total volume of earthwork then is divided by the productive capacity of the available equipment (table XXVIII) to find the time required. An example of this computation follows:

Volume of excavation........................83,000 cubic yards
Available equipment ....7 scrapers, 8-cubic-yard
3 scrapers, 12-cubic-yard

Equipment capacity (from table XXVIII, 8-cubic-yard scraper capacity based on 600-foot average haul; 12-cubic-yard scraper capacity based on 1,000-foot average haul).

7 scrapers, 8-cubic-yard, each 80 cubic yards per hour ....= 560 cubic yards
3 scrapers, 12-cubic-yard, each 90 cubic yards per hour ....= 270 cubic yards

Total capacity per hour...................... 830 cubic yards
Capacity for 20-hour day = 20x830=16,600 cubic yards.
Time required: 83,000÷16,600=5 days.

(*b*) Where work must be done in a definite time, the total volume is divided by the time available for the operation to establish the volume required per day (or hour), and equipment having sufficient productive capacity is requisitioned.

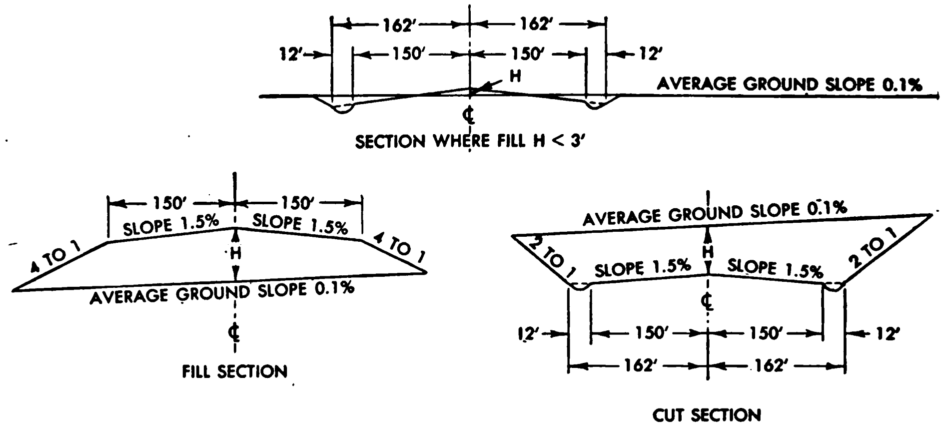
(4) Base courses and surfaces for runways, taxiways, hard standings, and roads are figured from length, width, and thickness previously decided and shown on sketch plans (par. 65). Productive capacities (table XXVIII) of the equipment to be used determine the time required.

170. DETAILED CONSTRUCTION ESTIMATES AND SCHEDULES.

a. General. Detailed construction estimates and operating schedules are set up when surveys and designs have been made into detailed plans. (See ch. 10.)

b. Information required. The preparation of construction estimates and schedules should be started as soon as design and plans provide enough information. For instance, when the grade line is established all estimates and schedules relating to earthwork can be started. Minimum information required for complete estimation and scheduling are summarized as follows: (1) Landing strip lay-out, profile, and typical section (fig. 129). Detailed drawings will show the dimensions and data listed below.

(*a*) Landing-strip length and width.
(*b*) Runway length and width.
(*c*) Clear zone length.
(*d*) Center-line profile and proposed grade line.



AVERAGE DEPTH OF CUT OR HEIGHT OF FILL IN FEET	VOLUMES IN CUBIC YARDS PER 100 FEET OF LENGTH			
DIMENSION H	FILL	CUT	FACTOR CUT TO FILL	CUT TIMES FACTOR
FILL – 0	0	1,520	0.8	1,215
CUT – 0	0	1,520	0.8	1,215
FILL – 1	250	540	0.8	432
CUT – 1		2,765	0.8	2212
FILL – 2	980	55		44
CUT – 2		4,000	0.8	3,200
FILL – 3	2,095			
CUT – 3		5,280	0.8	4,225
FILL – 4	3,240			
CUT – 4		6,580	0.8	5,265
FILL – 5	4,420			
CUT – 5		7,860	0.8	6,290

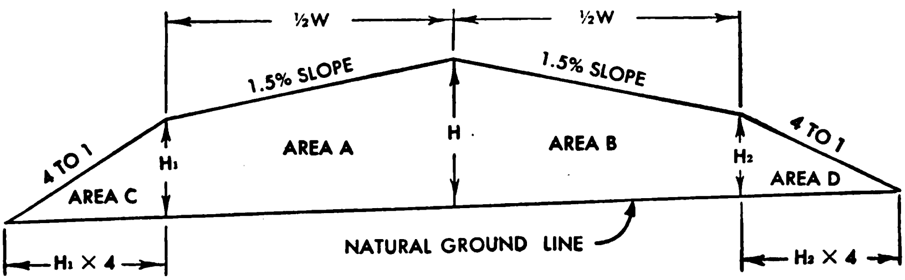
FACTOR OF CUT TO FILL BASED ON 125 CU. YDS. OF EXCAVATION REQUIRED TO MAKE 100 CU. YDS. OF FILL ($\frac{100}{125}$ = 0.8). CUT TIMES FACTOR GIVES VOLUME OF FILL THAT CAN BE MADE FROM CUT.

① *Center-line cut and fill table.*

Figure 128. Method of making quick preliminary estimate of earthwork.

(*e*) Shape of cross section and slopes.
(*f*) Width of shoulders and graded areas.
(*g*) Drainage channels.
(*h*) Base-course thickness and type.
(*i*) Type and dimensions of surface treatment or pavement.
(*j*) Location and type of clearing.
(*k*) Side-clearance requirements.

(2) Additional detailed information should include:
(*a*) Location of proposed material sites.
(*b*) Location of supply dumps and depots.
(*c*) Water sources for construction and personnel.
(*d*) Lists of organic and Class IV equipment available.
(*e*) Surveys of pit sites and necessary access roads.



AREA $A = \frac{H+H_1}{2} \times \frac{1}{2} W$

AREA $B = \frac{H+H_2}{2} \times \frac{1}{2} W$

AREA $C = \frac{H_1 \times 4}{2} \times H_1$

AREA $D = \frac{H_2 \times 4}{2} \times H_2$

TOTAL END AREA $= \frac{H+H_1}{2} \times \frac{1}{2} W + \frac{H+H_2}{2} \times \frac{1}{2} W + \frac{H_1 \times 4}{2} \times H_1 + \frac{H_2+4}{2} \times H_2$ (IN SQ. FT.)

TO FIND THE VOLUME BETWEEN TWO STATIONS 100 FEET APART USING AVERAGE END AREAS:

LET X = END AREA IN SQUARE FEET AT ANY STATION

X_1 = END AREA IN SQUARE FEET AT THE NEXT STATION

THEN $\frac{X+X_1}{2}$ = AVERAGE END AREA IN SQUARE FEET

$\frac{X+X_1}{2} \times 100$ = VOLUME IN CUBIC FEET FOR A 100-FOOT STATION

$\frac{X+X_1}{2} \times \frac{100}{27}$ = VOLUME IN CUBIC YARDS FOR A 100-FOOT STATION

② *Method of calculation.*

Figure 128. Continued.

(*f*) Required completion time.

(3) Detailed estimates for taxiways, hard standings, and roads require similar information.

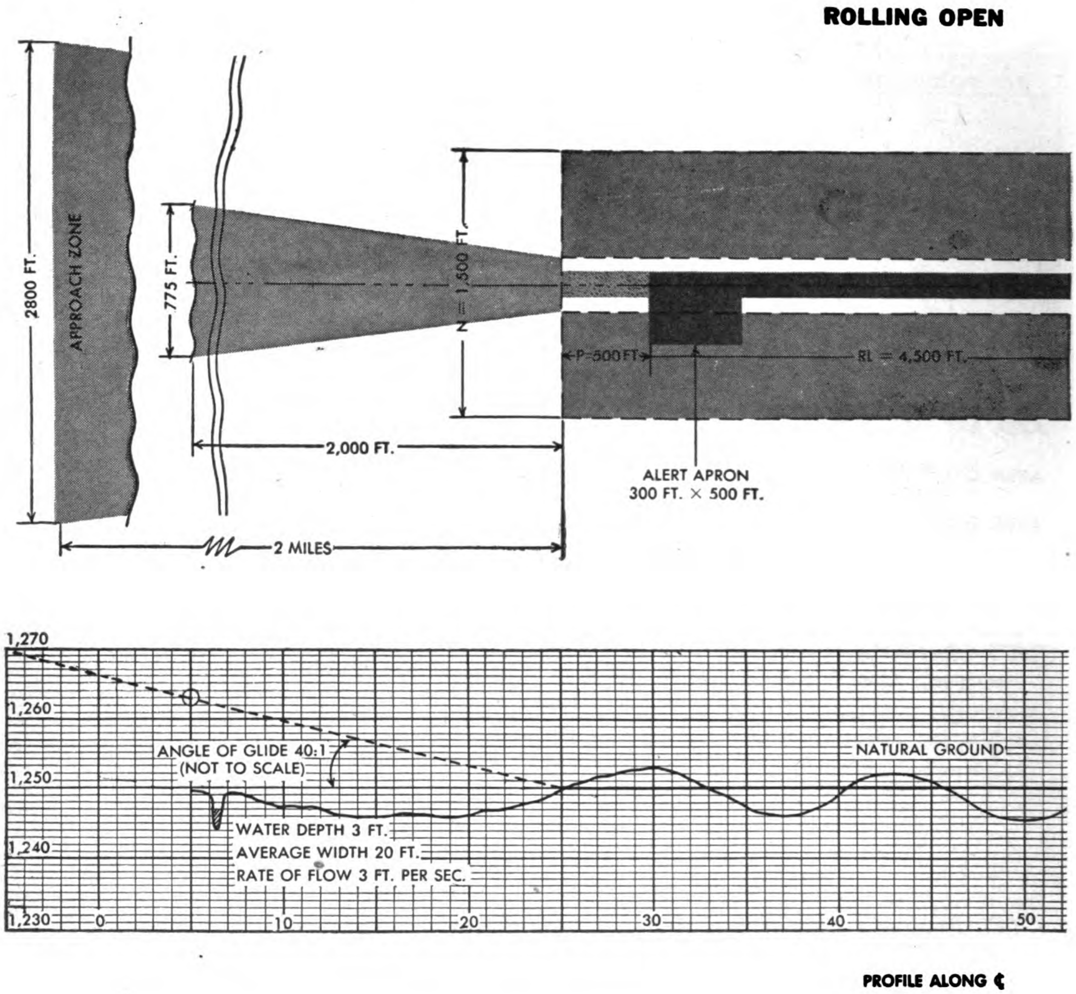
171. PROCEDURE FOR ESTIMATING AND SCHEDULING. Sequence of preparation and information contained in schedules and estimates are detailed below. Examples of charts and schedules shown are flexible and should be amended or extended in accordance with job requirements.

a. Estimation of materials and equipment. (1) All proposed operations are listed on the form in the sequence in which they are to be undertaken.

(2) Quantities involved in each operation are calculated from dimensions established by surveys and plans and entered on the form.

(3) Equipment necessary for the operation is listed and its estimated productive capacity (table XXVIII) is entered on the form.

(4) Equipment requirements for each operation are planned around the equipment unit which limits the operation. For instance, earth-moving operations are based on the volume of material that can be excavated and placed

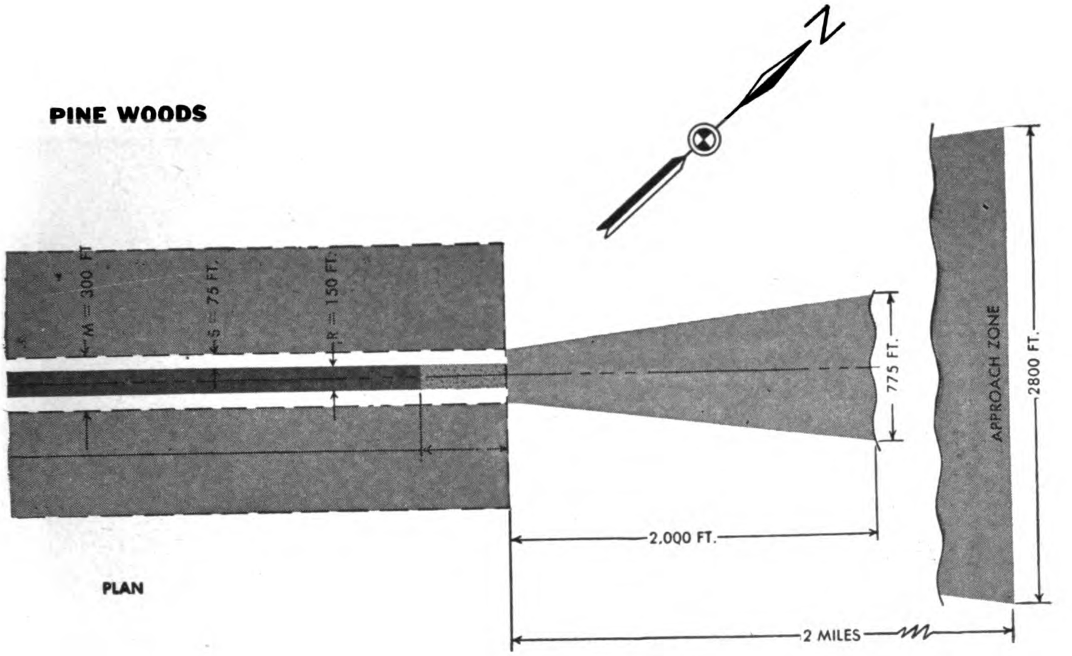


NOTES

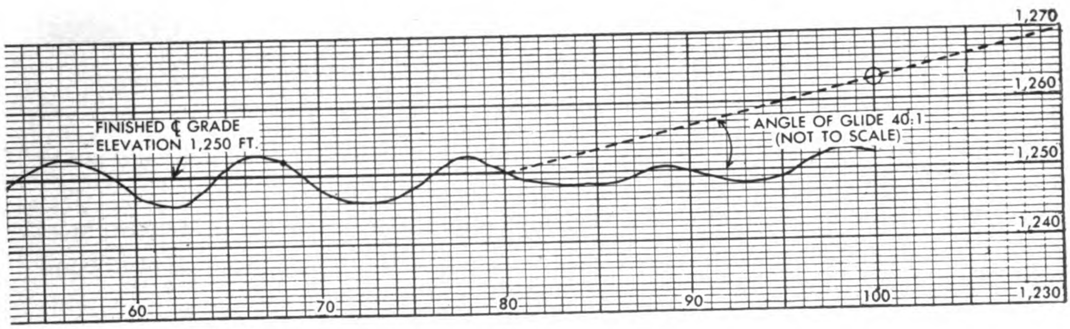
CLEARING OR TOPPING REQUIRED FOR SIDE CLEARANCE AND APPROACHES:

1. SIDE CLEARANCE AT 7:1 UNOBSTRUCTED.
2. GLIDE ANGLE OF 40:1 IS OBSTRUCTED BY TREES HAVING A MAXIMUM HEIGHT OF 50 FEET.
3. AREA OF TOPPING REQUIRED IN EACH APPROACH ZONE:
   LENGTH = 2,000 FEET (DISTANCE AT WHICH A 40:1 SLOPE IS 50 FEET HIGH)
   WIDTH = 300 FEET AT END OF LANDING STRIP
   WIDTH = 775 FEET AT 2,000 FEET BEYOND END OF LANDING STRIP.
   AREA = $\frac{300 + 775}{2} \times 2{,}000 = 1{,}075{,}000$ SQ. FT. = 22.1 ACRES.

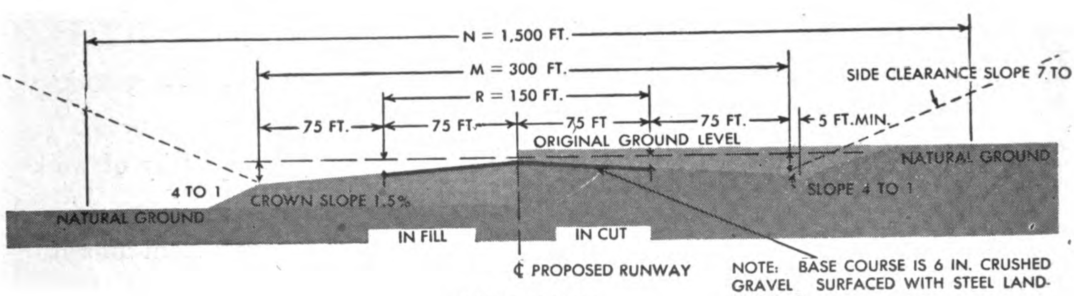
Figure 129. Plan lay-out, profile, and typical section of a landing strip.



PLAN



OF PROPOSED RUNWAY



TYPICAL SECTION

Figure 130. Earth-moving equipment operating in a select-material pit.

in fills or disposed of in waste areas by the scrapers or other available pieces of earth-moving equipment (fig. 130).

The number of scrapers employed determines the number of tractor units required. The amount of material placed in fill determines the amount of compaction equipment needed, the volume of water required, and the units required to haul and distribute the water. Similarly, when crushed rock or gravel is being employed, the hauling equipment, watering and compaction units, and power shovels or other loading units are based on the productive capacity of the crusher or processing plant.

(5) The number of machine units is assigned in accordance with quantities involved and the time which can be allotted to the task.

(6) Machine hours required are obtained by dividing the quantity of work to be done by the productive capacity of the machines.

(7) All other items on the chart then are derived in sequence from information already entered.

(8) A sample chart with a few typical entries is shown in table XXIV. A complete chart includes all operations, quantities, and equipment involved in the construction.

b. Construction operation schedule. After the estimate of materials and equipment has been made the construction operation schedule is prepared. This schedule establishes the total job time, coordinates equipment assignments

Table XXIV. Estimate of material and equipment.

Operation	Material				Equipment		Number machine units used	Machine hours required	Number days required (20-hr. day)	Machine operators (10-hr. shift)
Description	Quantity	Unit	Quantity	Unit	Description	Productive capacity				
Clearing and grubbing	38	Acre	---	2	Tractor, 80 dbhp, with angledozer	0.5 acres per hr.	2	152	152 ÷ 2 ÷ 20 = 3.8	4
				1	Tractor, 30 dbhp		1	76	76 ÷ 20 = 3.8	2
				1	Rooter, towed		1	76	76 ÷ 20 = 3.8	—
				1	Harrow, disk		1	76	76 ÷ 20 = 3.8	—
Ditching, intercepting, and outfall	5,600	Cu. yd.	--	--	Ditching machine	35 cu. yd. per hr.	1	160	160 ÷ 20 = 8.0	2
Earth moving	100,000	Cu. yd.	—	—	Scraper, 8-cu.-yd., towed	80 cu. yd. per hr.	7	770	770 ÷ 7 ÷ 20 = 5.5	—
					Tractor, 80 dbhp		7	770	770 ÷ 7 ÷ 20 = 5.5	14
					Scraper, 12-cu.-yd., motorized	120 cu. yd. per hr.	3	330	330 ÷ 3 ÷ 20 = 5.5	6
					Tractor, 80 dbhp, pusher (1 per three 12-yd. scrapers)		1	110	110 ÷ 20 = 5.5	2

and sequence of construction operations, and provides a means for checking daily progress against scheduled time. The method of preparing the schedule is outlined below.

(1) A chart is prepared listing all construction operations in the same sequence used in preparing the estimate of materials and equipment (table XXIV). Two horizontal spaces are provided opposite each operation so estimated time may be compared with actual progress.

(2) Priorities determine the sequence of construction of landing strip, taxiways, hard standings, and roads. The equipment needed for an operation (table XXIV) combined with the time when the equipment needed can be made available from other work determine the starting time for each operation. After the starting time has been determined the length of time to be plotted on the chart is obtained from the estimate of materials and equipment (table XXIV). Some operations such as clearing, grubbing, and drainage may be undertaken simultaneously, while other operations will overlap. For instance, rough grading operations may be under way at one end of a landing strip while subgrade preparation is in progress at the other.

(3) Operations should be scheduled to utilize all available equipment and personnel, if possible. Available equipment is assigned in order of urgency of task. As an example, it may be necessary to employ hand methods on portions of the work to release equipment for heavier and more urgent work.

(4) Progress of each operation should be charted each day and compared with scheduled time. Progress is plotted as a proportion of work done to total estimated work. Thus, if the progress line plotted on the chart on Saturday is at the point which should have been reached on Friday, the job is lagging and ways of accelerating production must be found.

(5) A sample chart with a few typical entries is shown in table XXV.

c. Equipment requirements. (1) Day-by-day equipment requirements are tabulated from information in the construction operation schedule (table XXV) and the estimate of materials and equipment (table XXIV). The period that equipment is required is taken from the schedule and the type of equipment and number of units required are obtained from the estimate.

(2) Identical items of equipment are tabulated together, regardless of operational use. In this way the total required number of units of any one type is summarized by days. Any discrepancy between available equipment and job needs is apparent by comparison.

(3) Assignment of equipment is made from definite sources to avoid confusion.

(4) The equipment schedule should be made up for periods of 1 week and as far in advance as possible. Variations from the scheduled use of equipment must be corrected as work progresses.

(5) Equipment is requisitioned from depots or stock piles on the basis of the schedule. This is done as early as possible to assure possession of such items in time for use.

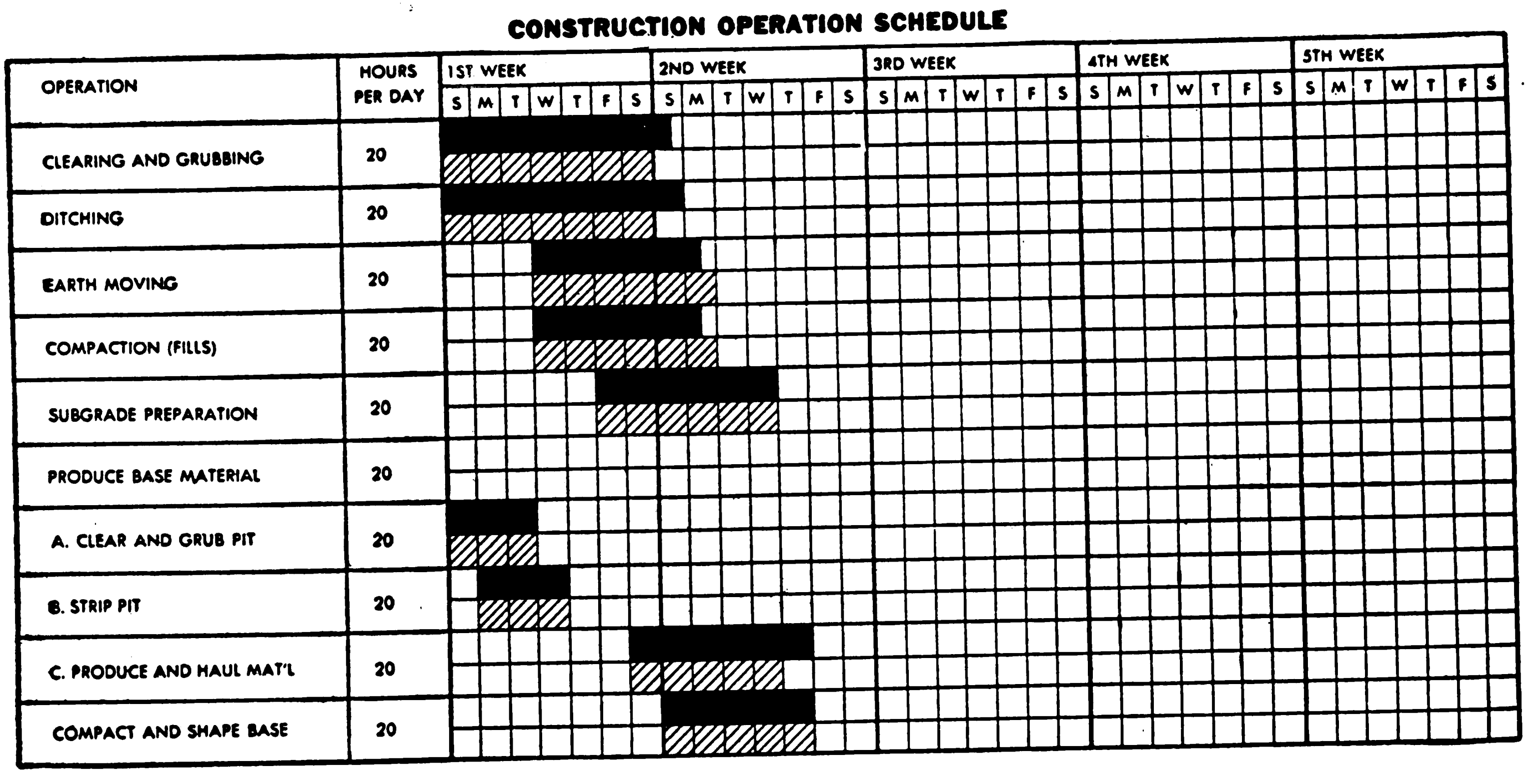


Table XXV. Construction operation schedule.

(6) A sample chart with illustrative entries is shown in table XXVI.

Table XXVI. Equipment requirements.

Item of equipment	Operational use	Source of equipment	Period: First week Number of units required						
			Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
Tractor, 80 dbhp, with angle-dozer	Clearing and grubbing	H and S	2	2	2	2	2	2	2
Tractor, 80 dbhp, scraper	Earth moving	(Co. A-3) (Co. B-3) (Co. C-1)				7	7	7	7
Tractor, 80 dbhp, pusher	Earth moving	Co. C				1	1	1	1
Tractor, 30 hp	Clearing and grubbing	H and S	1	1	1	1	1	1	1

d. Daily requirements of equipment, fuel, operators, and labor. (1) A tabulation of equipment, fuel, operators, and labor required is prepared from information available in estimate of materials and equipment (table XXIV), construction operation schedule (table XXV), and equipment requirements (table XXVI). Needs for equipment, fuel, and personnel undergo daily changes as operations progress. The construction operation schedule will indicate the amount of change required each day.
(2) Fuel requirements must be planned sufficiently in advance of operations to assure delivery from the service center as required. The daily requirements of each week should be consolidated a week in advance, where practicable.
(3) Personnel requirements also are consolidated for each week to assure proper commitment of troops necessary for operation.
(4) Personnel other than equipment operators can be estimated from standing operating procedures of the organization.
(5) Average working strength of lettered companies is estimated at 120 men, and of a headquarters and service company at 110 men.
(6) A sample chart with typical entries is shown in table XXVII.

172. WATER SUPPLY FOR CONSTRUCTION. a. General. The volume of water needed in constructing an airdrome requires special consideration and planning. Individual sites have different requirements depending on the type of work to be performed, weather conditions, and methods and equipment employed. Optimum moisture requirements for earth fills (par. 10, app. III), water required in subgrade preparation (par. 126), and placement of base courses (ch. 15) all must be estimated properly so work

Table XXVII. Requirements of equipment, fuel, and labor.

Operation	Equipment		Schedule		Machine hours per day	Fuel per hour each unit		Total fuel		Operators		Labor	
	Description	Number required	Hours per day	Number of shifts		Gas	Dies	Gas	Dies	Number per unit	Total	Number per shift	Total
Clearing and grubbing	Tractor, 80 dbhp with angledozer	2	20	2	40		4.4		176	2	4	4	8

will not be delayed because of insufficient water. An illustrative example of water required for compacting fills on a landing strip follows:

(1) Volume of excavated material to be placed and compacted—100,000 cubic yards.

(2) Loose dry weight of material—2,200 pounds per cubic yard.

(3) Water required to bring to optimum—10 percent (by weight).

(4) Water required per cubic yard—220 pounds = 26 gallons.

(5) Total water required—100,000 x 26 = 2,600,000 gallons.

(6) Organic equipment of an engineer aviation battalion will place a maximum of 9,000 cubic yards of earth per 10-hour shift (table XXVIII).

(7) 9,000 x 26 = 234,000 gallons of water required per 10-hour shift, or 23,400 gallons per hour.

b. Planning for use. (1) All possible sources of raw water in the immediate vicinity should be explored. Quantities available, access roads, and pumping equipment (table LXXVIII) necessary should be noted.

(2) The 1,500-gallon trailer tank and trailer-mounted pump with distributor attachments usually will have to be augmented by mounting 750-gallon tanks in dump or cargo trucks to obtain sufficient water for the work.

(3) Water pumping and distributing equipment should be ready to operate when embankment operations begin.

(4) The possibility of piping and pumping water from its source to convenient points at the construction site should be investigated. If piping is practicable, the number of tank units required for hauling can be reduced materially.

173. PRODUCTIVE CAPACITY OF EQUIPMENT. Rated capacities of equipment are based on average materials, efficient supervision and operation, and proper equipment maintenance. Any change from these prerequisites affects the rated capacity. Estimates and schedules for equipment must be based on a working knowledge of materials to be handled, type and condition of equipment, and quality of supervision and operation. Table XXVIII lists normal equipment production. Production figures given should be modified where necessary to suit conditions peculiar to the job.

Table XXVIII. Productive capacity of equipment.

Equipment item	Rate-units per hour	Unit	Conditions
CLEARING AND GRUBBING			
Hand tools	125 man-hour 350 man-hour 1750 man-hour	Acre Acre Acre	Light clearing. Medium clearing. Heavy clearing.
Tractor, 70- to 90-dbhp, dozer	0.25	Acre	Medium clearing.
Tractor, 30-dbhp	0.50	Acre	Pulling disk.
Mower with tractor, 30-dbhp	2.00	Acre	Cutting weeds and grasses.
Tractor, 70- to 90-dbhp, dozer	1.00	Acre	Light stripping
DRAINAGE DITCHES			
Ditching machine, wheel-type	150 125 75	Cu. yd. Cu. yd. Cu. yd.	Sandy soil. Common earth. Hard or frozen earth.
Ditching machine, ladder-type	50 45	Cu. yd. Cu. yd.	Sandy soil. Common earth.
Shovel or dragline, ¾-cu. yd.	45 75	Cu. yd. Cu. yd.	Hard digging. Easy digging.
Shovel or dragline, 2-cu. yd.	125 200	Cu. yd. Cu. yd.	Hard digging. Easy digging.
Grader, motorized	450 300	Cu. yd. Cu. yd.	"V" ditches, sandy soil. "V" ditches, common earth.
Grader, towed type	300	Cu. yd.	Common earth.
EXCAVATION			
Tractor, 70- to 90-dbhp, with angledozer	130 80 50	Cu. yd. Cu. yd. Cu. yd.	50-ft. level haul, common earth. 100-ft. level haul, common earth. 200-ft. level haul, common earth.
Scraper, towed, 8-cu. yd., with tractor, 70- to 90-dbhp.	95 80 60	Cu. yd. Cu. yd. Cu. yd.	500-ft. level haul, common earth. 600-ft. level haul, common earth. 800-ft. level haul, common earth.
Scraper, motorized, 12-cu. yd., with tractor, 70- to 90-dbhp, pusher	115 90 75	Cu. yd. Cu. yd. Cu. yd.	800-ft. level haul, common earth. 1000-ft. level haul, common earth. 2000-ft. level haul, common earth.

Table XXVIII. Productive capacity of equipment.—Continued.

Equipment item	Rate-units per hour	Unit	Conditions
EXCAVATION—*Continued*			
Shovel, or dragline, ¾-cu. yd.	45 75	Cu. yd. Cu. yd.	Hard digging. Easy digging.
Shovel or dragline, 2-cu. yd.	125 200	Cu. yd. Cu. yd.	Hard digging. Easy digging.
EMBANKMENT			
Tractor, 70- to 90-dbhp, with angledozer	300	Cu. yd.	Spreading material.
Roller, sheepsfoot, two drum-in-line, towed by tractor, 70- to 90-dbhp	250 200 150	Cu. yd. Cu. yd. Cu. yd.	9-in. loose layers, 8 passes. 9-in. loose layers, 10 passes. 9-in. loose layers, 12 passes.
Pump, trailer, mtd., water-distributor	350	Gpm	Moisture varies with material.
SUBGRADE PREPARATION			
Grader, towed-type	400	Sq. yd.	Scarify and shape.
Grader, motorized	400	Sq. yd.	Scarify and shape.
Roller, sheepsfoot, two drum-in-line, towed by tractor, 70- to 90-dbhp	650 540 450	Sq. yd. Sq. yd. Sq. yd.	6-in. layers, 8 passes. 6-in. layers, 10 passes. 6-in. layers, 12 passes.
Roller, rubber-tired, with tractor, 30-dbhp	3000	Sq. yd.	5 mph, 5 passes.
Roller, road, tandem, 5- to 8-ton	1000	Sq. yd.	3 mph, 5 passes.
Rotary tiller, tractor, 30-dbhp	1750	Sq. yd.	6-in. depth, 3 mph, 3 passes.
Pump, trailer-mounted, water-distributor	350	Gpm	Moisture varies with material.
BASE COURSE CONSTRUCTION			
Tractor, 70- to 90-dbhp, with angledozer	300	Cu. yd.	Spread material.
Grader, motorized Grader, motorized	200 450	Cu. yd. Sq. yd.	Spread material. Shaping surface.
Roller, road, tandem, 5- to 8-ton Roller, road, tandem, 5- to 8-ton	300 75	Sq. yd. Cu. yd.	Compacting gravel. Compacting macadam.

Table XXVIII. Productive capacity of equipment.—Continued.

Equipment item	Rate-units per hour	**Unit**	Conditions
BASE COURSE CONSTRUCTION—*Continued*			
Roller, rubber-tired, tractor, 30 dbhp	1500	Sq. yd.	Compacting gravel, 10 passes.
Pump, trailer mounted, water-distributor	350	Gpm	Moisture varies with material.
SURFACE TREATMENTS			
Sweeper, tractor, 30-dbhp	2500	Sq. yd.	Sweeping compact base.
Distributor, trailer-mounted	2500	Sq. yd.	0.1 gal. per sq. yd., 24-ft., spray.
	1250	Sq. yd.	0.2 gal. per sq. yd., 24-ft. spray.
Spreader, aggregate, traction-powered	5000	Sq. yd.	Spreading cover aggregates.
Roller, road, tandem, 5- to 8-ton	3000	Sq. yd.	Rolling aggregate, 3 mph, 3 passes.
Roller, rubber-tired, tractor, 30-dbhp	3000	Sq. yd.	Rolling aggregate, 5 mph, 5 passes.
PAVEMENT CONSTRUCTION			
Distributor, trailer-mounted	1250	Sq. yd.	0.2 gal. per sq. yd., 24-ft. spray.
Grader, motorized	150	Sq. yd.	Mixed in place, 2-in. bituminous material.
Rotary, tiller, tractor, 30-dbhp	100	Cu. yd.	Mixing bituminous materials.
Mixer, travel-plant, asphalt	120	Ton	Mixed in place by travel plant.
Roller, road, tandem, 5- to 8-ton	1500	Sq. yd.	Rolling pavement, 3 mph, 6 passes.
Roller, rubber-tired, tractor, 30-dbhp	3000	Sq. yd.	Rolling pavement, 5 mph, 5 passes.
Mixer, concrete, 14-cu. ft.	20	Cu. yd.	1 batch every 2 min.
Mixer, concrete, 14-cu. ft.	10	Cu. yd.	1 batch every 3 min.
Paver, concrete, 34-cu. ft.	40	Cu. yd.	1 batch every 1.75 min.
Finisher, asphalt, 12-ft.	100	Ton	Finishing-plant mix material.
Finisher, concrete, 20- to 25-ft.	200	Lin. ft.	Capacity depends on paver.
Spreader, concrete, 20- to 25-ft.	200	Lin. ft.	Capacity depends on paver.

Table XXVIII. Productive capacity of equipment.—Continued.

Equipment item	Rate-units per hour	Unit	Conditions
AGGREGATE PRODUCTION			
Crusher, two-unit, 25 tons per hr.	15	Ton	1-in. aggregate, screened.
	20	Ton	1½-in. aggregate, screened.
	30	Ton	2½-in. aggregate, screened.
Crusher, nine-unit, 150 tons per hr.	40	Ton	½-in. aggregate, screened, washed.
	100	Ton	1¼-in. aggregate, screened, washed.
	240	Ton	3-in. aggregate, screened, washed.
Compressor, 105-cfm	105	Cfm	At sea level.
	90	Cfm	5000 ft. above sea level.
Compressor, 315-cfm	315	Cfm	At sea level.
	265	Cfm	5000 ft. above sea level.
Drill, rock, 35-lb. class	20	Lin. ft.	1¾-in. hole, max. depth 48 ft. Requires 40 to 60 cfm of air.
Drill, rock, 45-lb. class	30	Lin. ft.	1¾-in. hole, max. depth 12 ft. Requires 70 to 90 cfm of air.
Loader, truck, bucket type	150	Cu. yd.	Loading trucks from stock pile.

CHAPTER 22

FACILITIES

174. GENERAL. The extent to which facilities are provided at any airdrome depends upon the type and use of the field. For advanced landing fields only items essential for air operation are installed at first, while for field and base airdromes more complete provisions are made. Generally the longer a field is in operation the more improvements will be installed and the more aircraft accommodated. The basic principles of construction in a theater of operations (ch. 6) and the general criteria for airdrome lay-out (ch. 7) apply to the construction of all facilities discussed in this chapter. Timber construction in tropical zones must take into consideration methods of termite control. Removal of all stumps, roots, and debris under and around structures will help. In locating and dispersing facilities advantage is taken of all available cover and concealment (fig. 13).

175. GASOLINE, GREASE, AND OIL STORAGE. a. General. The plan and lay-out of an airdrome always include areas for storage of gasoline, grease, and oil. These include a main storage area containing fuel for from 2 to 4 weeks of average operation, located from ½ to 4 miles from the runways; and an emergency storage area in the vicinity of the hard standings, containing fuel for 1 or 2 days operation.

b. Gasoline requirements. Requirements should be based upon actual operations experience wherever possible. The following are estimated gasoline requirements of different types of squadrons for 1 week's normal operation:

Fighter	10,000 gallons
Light bomber	20,000 gallons
Medium bomber	25,000 gallons
Heavy bomber	45,000 gallons

c. Gasoline storage. (1) The most common type of gasoline storage is in 55-gallon metal drums (fig. 131). Other less common means include cylindrical steel tanks (fig. 132) and collapsible synthetic rubber tanks (fig. 133). Drums and tanks may be laid on the ground or buried. If above ground level, a protective wall of earth or other material should be placed

Figure 131. Concealed fuel dump—gasoline stored in 55-gallon metal drums.

around the containers to protect them from bomb blast and fragments and confine any spilled gasoline. Buried tanks must be well anchored in locations where the ground-water table may rise above the bottom of tanks and float them when empty.

(2) Units of storage are low piles of 55-gallon drums or single tanks dispersed and concealed (fig. 134). If natural cover is not available, dispersion

Figure 132. Camouflaged cylindrical steel gasoline storage tank.

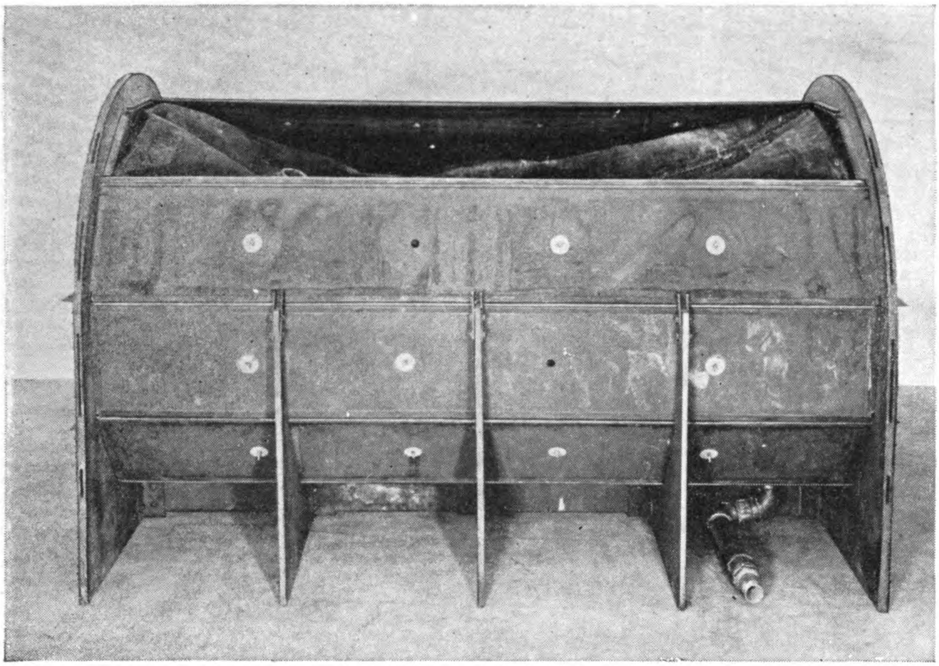


Figure 133. Portable 750-gallon synthetic rubber tank in plywood housing for gasoline storage.

alone is depended upon for protection (fig. 135). In main storage areas the maximum allowable quantity in one unit is 5,500 gallons or the capacity of one tank, whichever is greater. Minimum distance between units is 75 yards.

(3) Tank trucks normally are used to transport gasoline from the storage area to service the planes at their hard standings (fig. 136). If tank trucks are not available, fuel is taken to the planes in 55-gallon drums or in synthetic rubber or steel tanks mounted on trucks (figs. 137 and 138). Hand or power pumps are used to transfer fuel between containers and from container to plane (fig. 139).

(4) Gasoline may be transported and distributed by portable pipeline equipment obtained from depots. See TM 5–350 for detailed instructions for installation and operation of pipe lines.

(5) At storage sites located on a sidehill a gravity flow system for transferring gasoline from 55-gallon drums to storage tanks, and later from storage tanks to tank trucks may be constructed as shown in figure 140. The difference in elevation (A) between the collecting platform and storage tank, and between the tanks and outlet to tank truck (C) must be enough to provide hydrostatic head for adequate flow of gasoline through the pipe size used. The storage tank is placed 100 feet or more (B) from the collector platform. The distance (D) from the storage tanks to the tank-truck loading site depends upon the terrain and availability of service roads. Earth traverses are constructed between the collector platform and storage tanks to serve as a fire

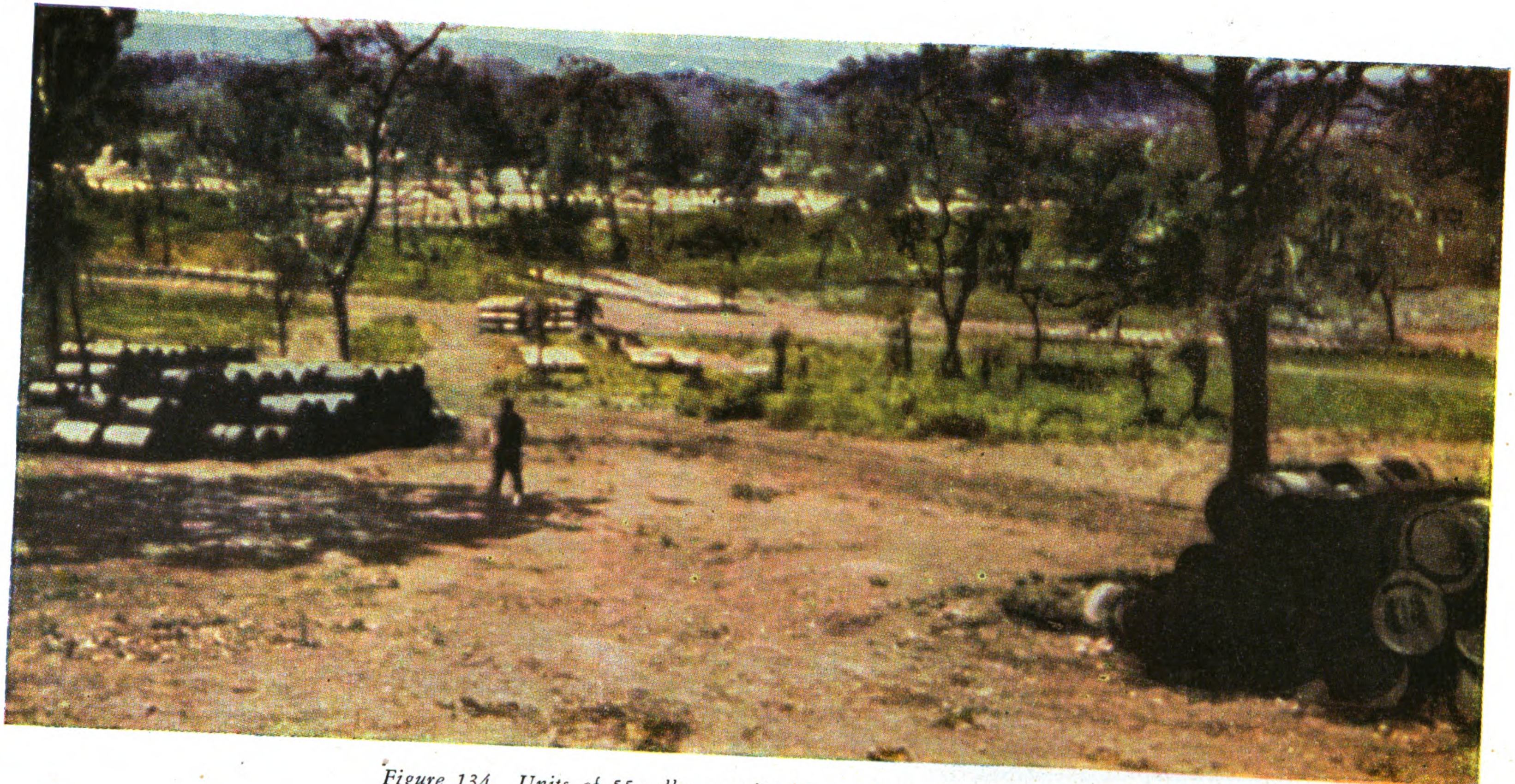


Figure 134. Units of 55-gallon gasoline drums dispersed and concealed.

Figure 135. 55-gallon gasoline drums dispersed in area with no natural concealment.

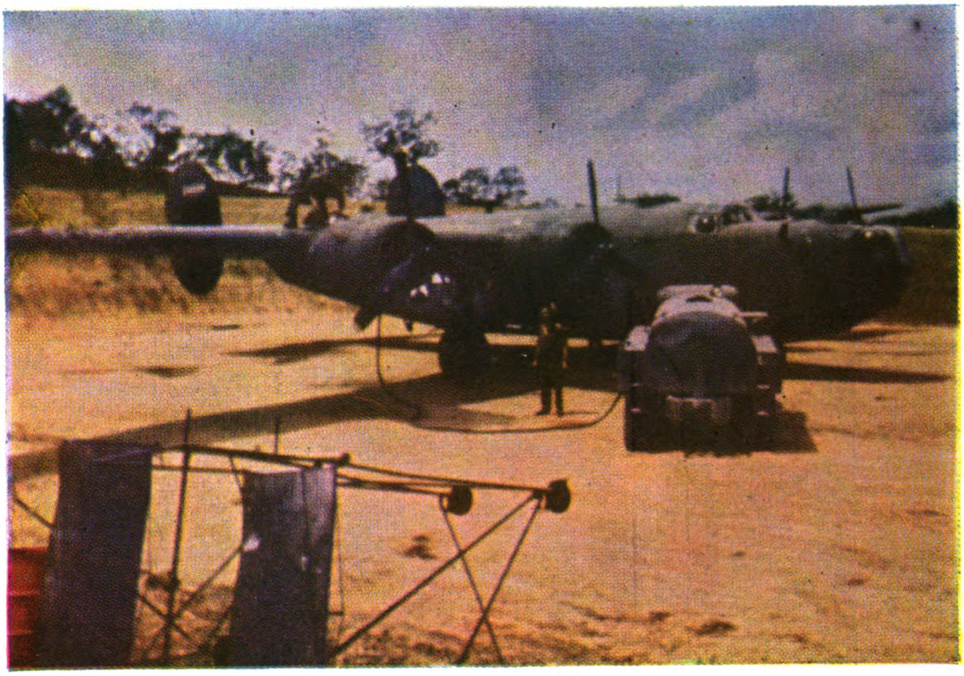


Figure 136. Tank truck servicing plane at hard standing.

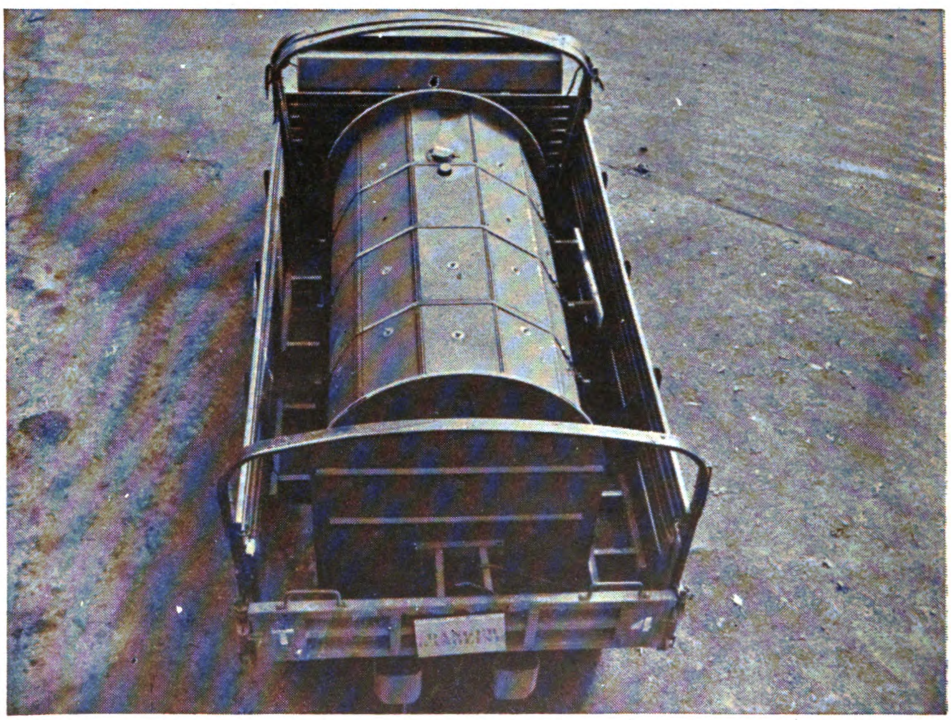


Figure 137. Portable 750-gallon synthetic rubber tank in plywood housing mounted on 2½-ton truck for transportation of gasoline.

Figure 138. Steel tank mounted on $2\frac{1}{2}$-ton truck for transportation of gasoline.

stop. Traverses, ditches, or natural drainage are utilized to divert gasoline from any vital installations in case of a leak or break in the tank or pipe line.

d. Grease and oil. Cans of grease and oil for lubrication are stored in the same manner as gasoline drums. They are transported to hard standings by truck.

Figure 139. Pumping gasoline from 55-gallon drums to tank truck.

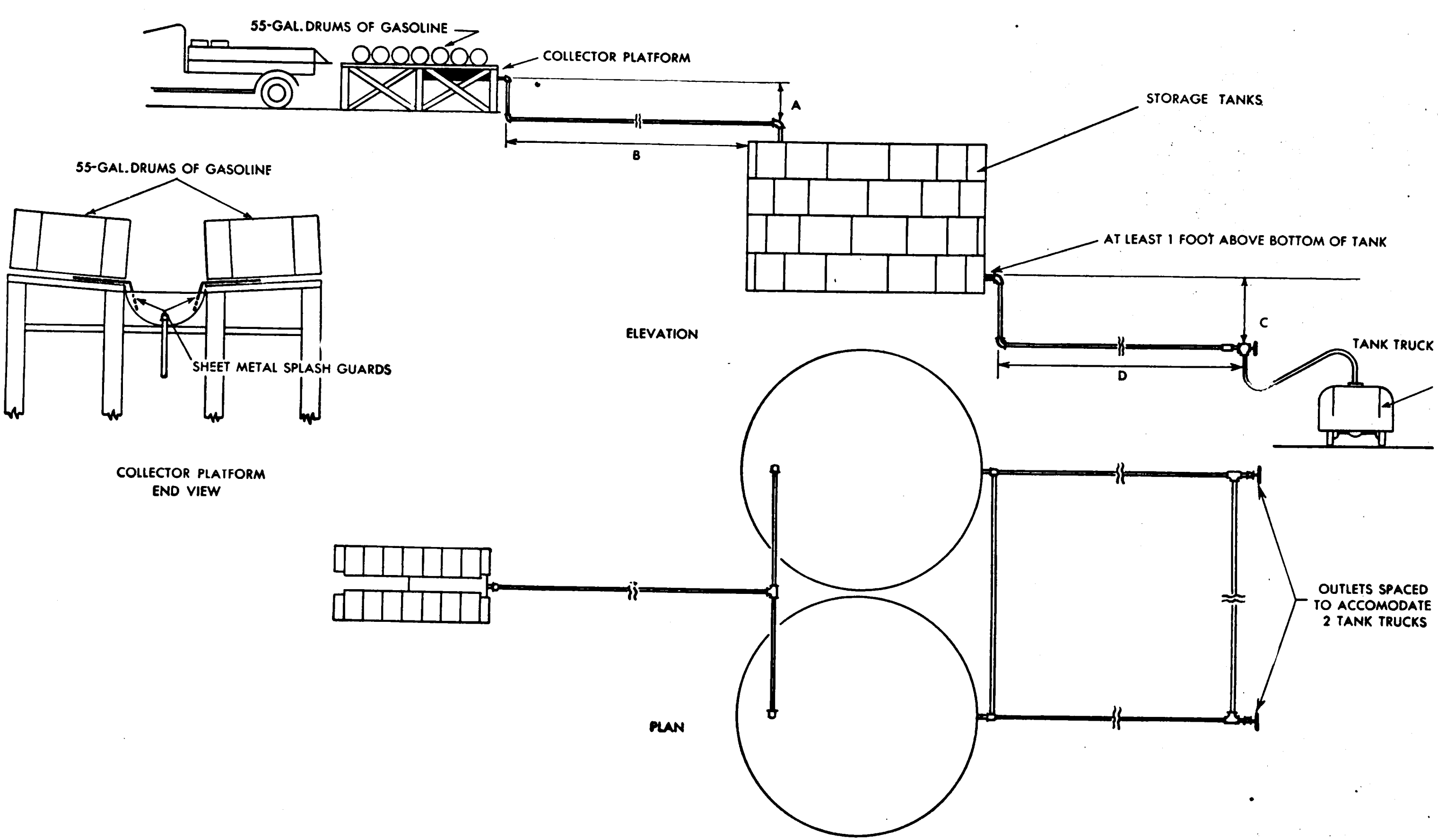


Figure 140. Schematic diagram of gravity-flow gasoline-collecting system.

Figure 141. Bomb storage unit.

176. BOMBS, AMMUNITION, AND CHEMICAL STORAGE. a. Bombs are stored in units in dispersed and concealed magazine areas 2 to 5 miles from the runway. Plans for lay-out and construction of magazine areas are worked out with the ordnance officer. A bomb-storage unit is a pile or stack of bombs (fig. 141). The weight of bombs in one unit is 50,000 to 75,000 pounds. Units are placed a minimum of 75 yards from one another. As soon as possible protective walls (fig. 142) are placed around each unit to protect the contents from bomb blast and fragments. Fins are stored detached from the bombs, to protect them from damage. Fuzes are stored separately in weatherproof structures. When the airdrome first is put in operation fuzes are stored in tents or existing buildings. As improvements of the airdrome are made, lumber, corrugated metal, concrete, or local materials may be used to provide buildings for dry storage (fig. 143).

b. Ammunition and chemicals are stored in magazine areas. They are spread over several individual sites to prevent one bomb hit destroying the total supply (fig. 144).

177. REPAIR OF AIRCRAFT. a. Maintenance of aircraft is performed at the hard standings (fig. 145). Portable nose hangars or improvised portable shelters which fit over the engine may be used to protect personnel from adverse weather. Mobile shops containing tools and necessary power equipment are transferred from plane to plane as needed. Aircraft requiring major repairs or overhaul are sent to rear-area depots if possible.

b. Two types of large portable combat hangar are available in rear areas. One type (fig. 146) is a steel framework supporting a canvas cover. It is

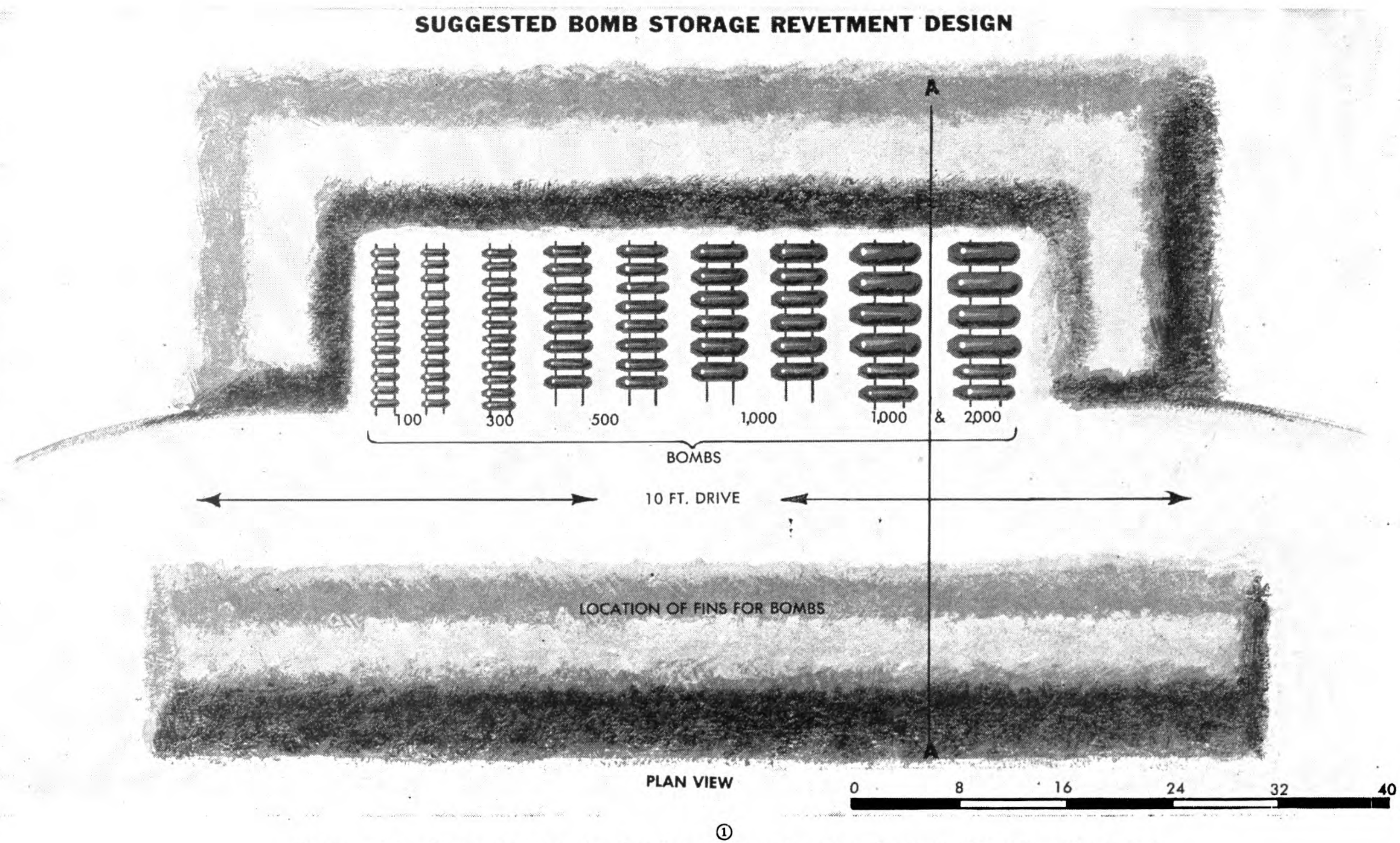
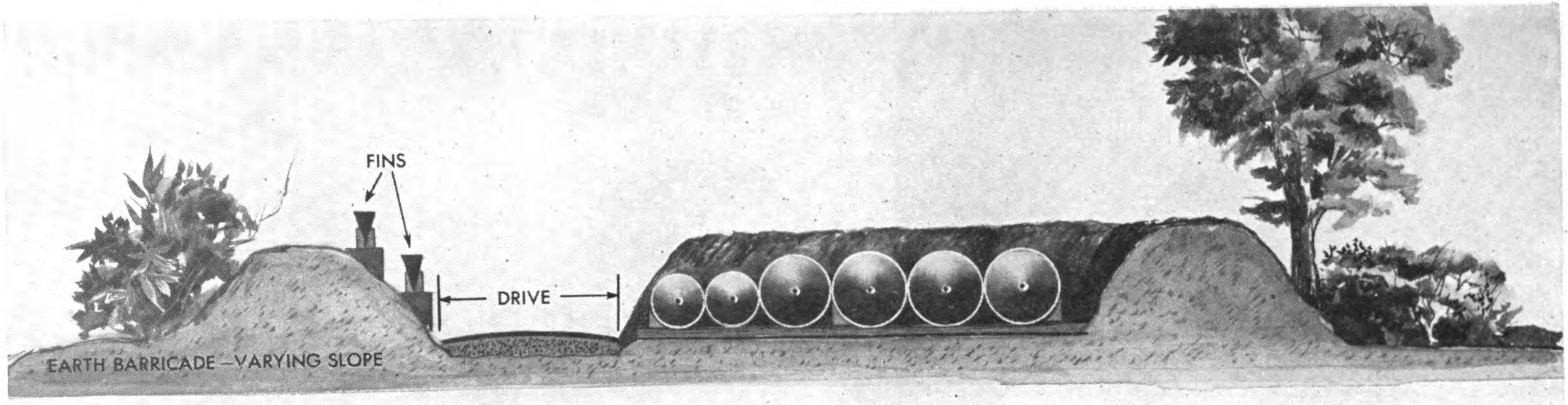
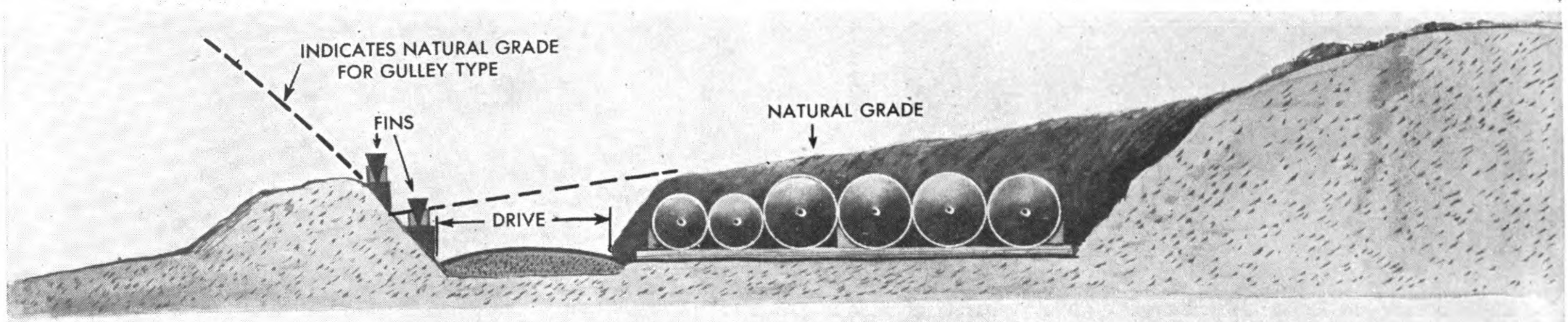


Figure 142. Protective pen for bomb storage unit. See drawing BG 784—Sheets 9.1 and 9.2 for reference on ordnance high explosive storage for dispersed airdromes.



SECTION ON LINE A-A
NO SCALE



SECTION SHOWING REVETMENT FOR HILLSIDE OR GULLEY.
NO SCALE

②

Figure 142. Continued.

Figure 143. Bomb fuze storage constructed in a sidehill.

132 feet across the base and 35 feet high at the center. It is built in sections, making the length variable depending upon the material available. In cold climates, wood sheathing may be substituted for or added to the canvas covering. Another type (fig. 147) is a series of semicircular steel arches covered with light metal sheeting. It is 150 feet wide at the base and 37 feet high at the center. It is built in 18-foot sections and its length may be any multiple of 18 feet, depending upon material available. The ends are covered by canvas.

Figure 144. Ammunition storage units dispersed and concealed.

Figure 145. Maintenance crew working on aircraft at hard standing.

178. MARKING AND LIGHTING RUNWAYS. a. Daylight operation. (1) For easy identification in daylight runways sometimes are marked. Instructions for marking usually are covered by special directives. Various symbols and methods are used.

(2) Materials for marking include cloth, canvas, oznaburg, sand, and stones. To provide contrast, marking materials are painted if necessary. Yellow paint generally is used because of its high visibility.

(3) Runways may be marked by **L**-shaped corner strips (fig. 24③), and straight strips along the end and sides. No above-ground objects are placed as markings on or near the runways.

(4) To aid pilots in gauging distance it is desirable to mark runways at points 1,000 feet in from each end. The 1,000-foot points usually are identified on both edges of the runway by a group of parallel stripes placed on the runway and parallel with its long axis. Each group of stripes consists of 15 stripes, each 6 inches wide, 100 feet long, and spaced 12 inches center-to-center.

b. Night operation. (1) Portable field-lighting sets are issued as air forces equipment. The set consists of marker, obstacle, approach, and beacon lights; cones; masts; power plant; and supplementary equipment such as cables, switches, guy lines, and extra parts. Location of obstacle lights depends upon the position and height of the obstacle. Where no obstacle exists the lights are placed up to 1,000 feet from the ends of the runway. Hoods are provided to be placed over the lights to direct one beam toward the landing aircraft. A series of small perforations project small rays of light in all directions to facilitate taxiing.

Figure 146. Portable combat hangar.

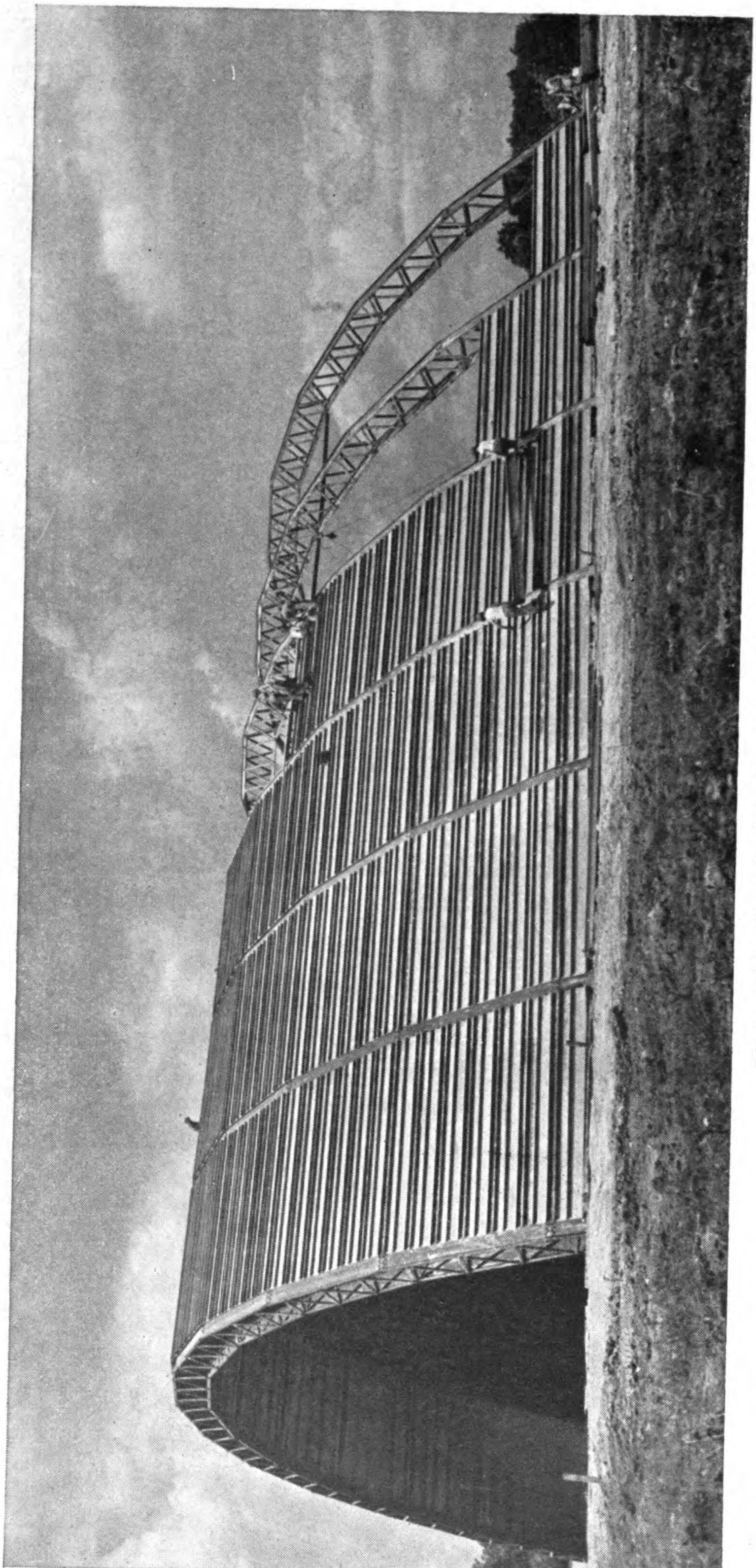


Figure 147. Portable metal-covered combat hangar.

733495°—47——18

(*a*) The approach light is a box-shaped device which projects toward the approaching airplane three separate, flat beams of light, one above the other. The top beam is yellow, the middle, green, and the bottom, red. The pilot sees the yellow beam when he is too high, the red when he is too low, and the green when he is coming in correctly.

(*b*) Beacon lights are placed up to 15 miles from the site to guide planes to the runway. They should be sited on high ground away from important objectives to which they might draw enemy fire. Under combat conditions, in which enemy aircraft are active at night, the beacons are moved daily.

(2) Expedients may be used for lighting if issue equipment is not available. Lanterns, smudge pots, vehicle headlights, or reflectors may be used to distinguish the runway edges. Reflectors also are convenient to place along taxiways and, at hard standings, to guide pilots in the dark. An electrical circuit may be laid around the runway with light globes spaced at regular intervals covered by improvised hoods made from cans. A searchlight pointed straight in the air sometimes is used as a substitute for beacon lights. The light is placed beyond the downwind end of the runway. When the pilot is oriented the light is lowered so its beam shines down the runway, thereby lighting it for him.

179. AIR FORCE SUPPLIES. Warehouses and open, covered, or enclosed storage areas are provided for storing air force supplies. Warehouses may be constructed from theater of operations plans (TM 5–280 and 5–281) or by local methods and material (fig. 148). Open storage areas are cleared of underbrush, smoothed and drained, and provided with dunnage or flooring if necessary. Covered storage consists of canvas or a framed roof placed over

Figure 148. Warehouse constructed of local material.

Figure 149. Covered storage constructed of local material.

the site (fig. 149). Drainage is provided for all storage sites and protective walls around them are added where required. Service roads to storage areas are provided.

180. OPERATIONS ROOM, PILOTS' ROOM, AND CONTROL TOWER. a. Operations and pilots' rooms are provided for each squadron and higher unit in buildings of theater of operations or native type construction. They may be in the same or in adjacent buildings. Figure 150 shows a typical fighter squadron operations which includes a pilots' room.

b. The control tower is located adjacent to any landing strip which requires traffic control, usually not nearer than 100 feet from the edge of the runway shoulder. Usually it is a covered and enclosed platform built as a self-supported structure, no higher than necessary to afford an unobstructed view of the runway (figs. 151 and 152). It has a switch for the runway lights, a telephone to the operations building, and facilities for radio and visual contact (fig. 153) with airplanes.

181. COMMUNICATIONS. a. Roads (see par. 57e). The road network is extended and improved as required by expansion of the airdrome.

b. Radio and telephone. The Signal Corps normally plans and installs telephone and radio facilities. Buildings to house these installations are constructed by aviation engineers (fig. 154). These buildings may be theater of operations type (TM 5–280 and 5–281) or of local type and materials.

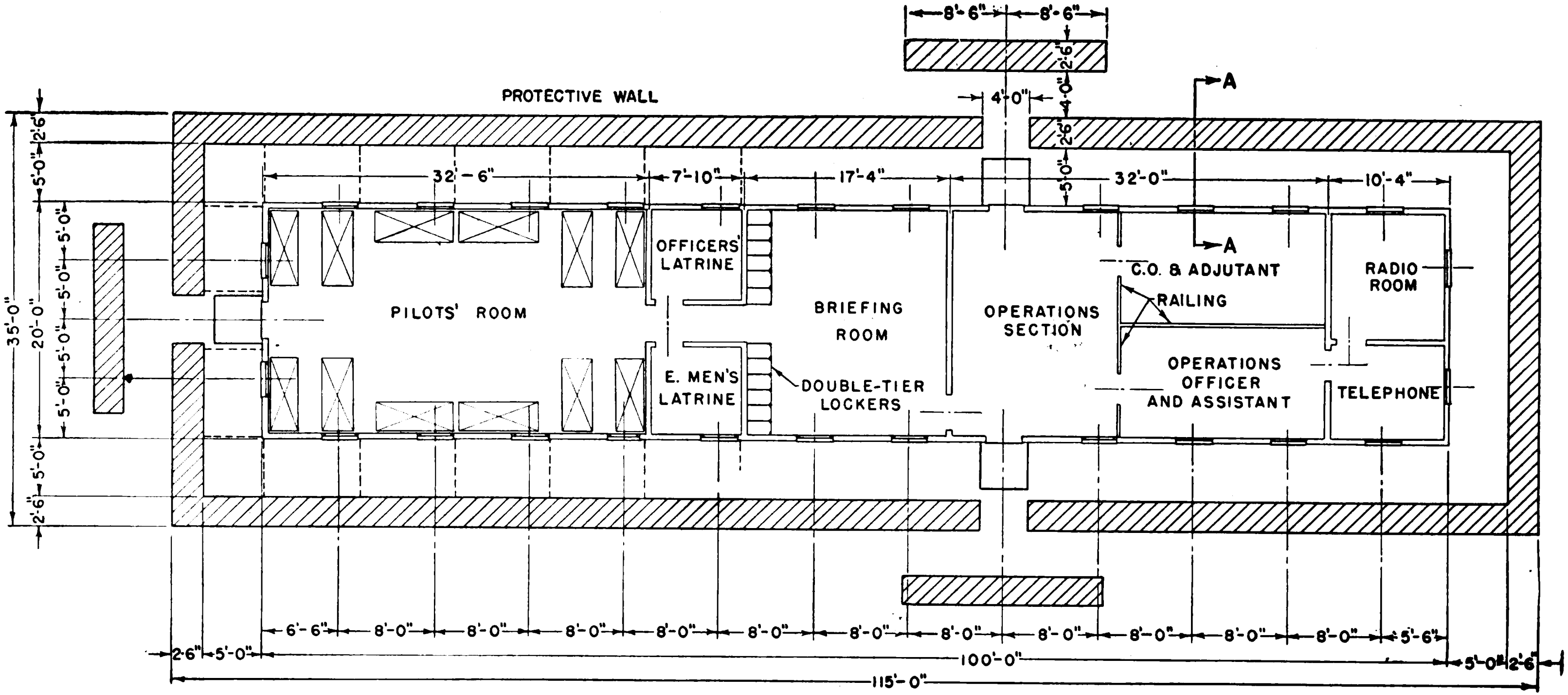


Figure 150. *Plan for operations building—fighter squadron. By rearrangement of partitions and facilities the building also will serve for bomber operations. For detail of protective wall see figure 175.*

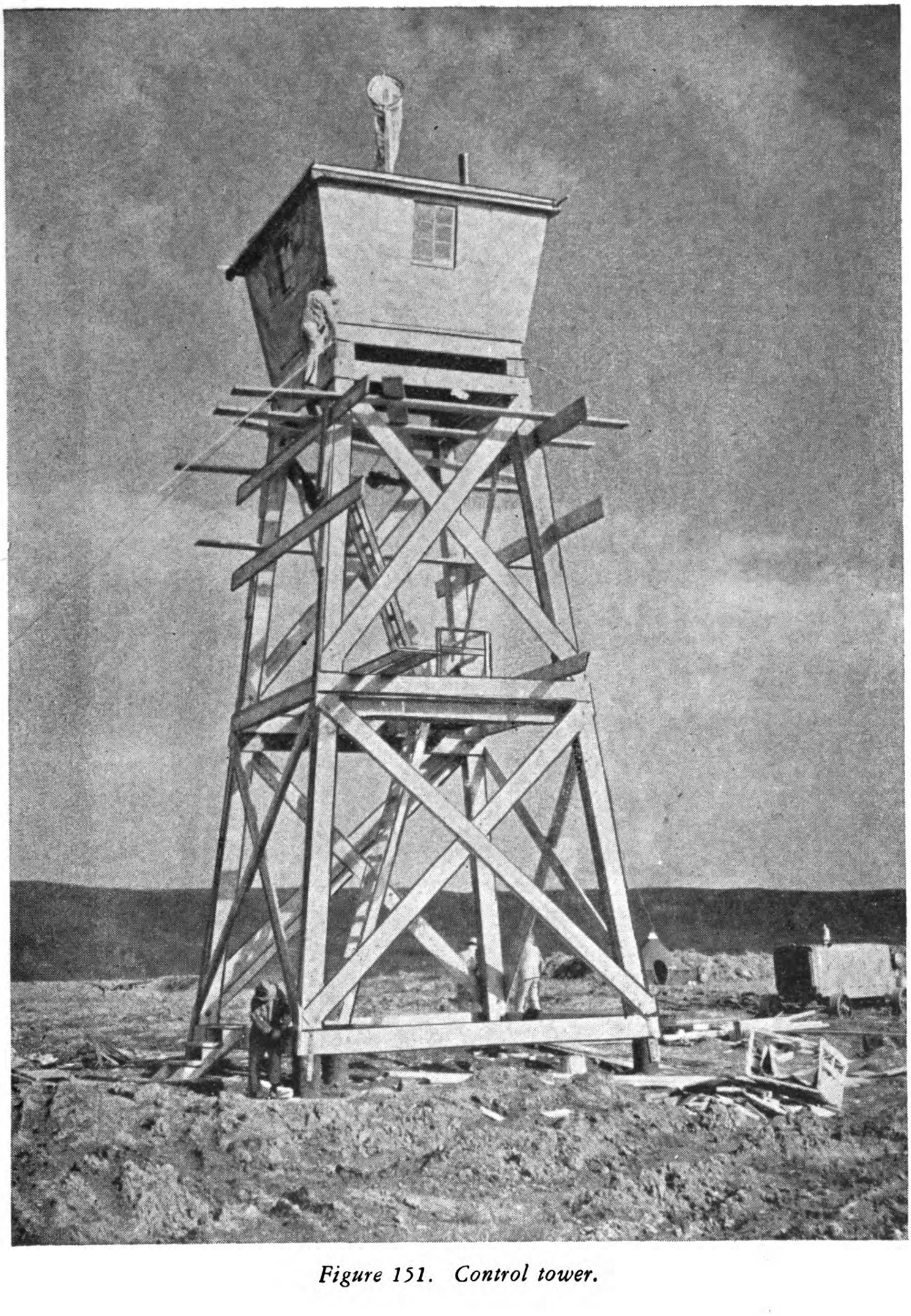


Figure 151. Control tower.

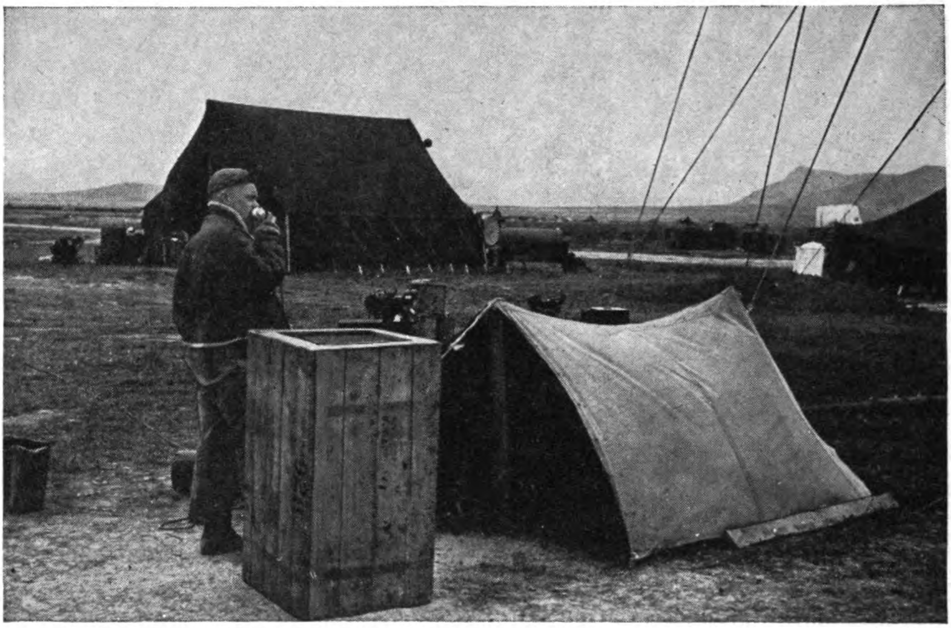


Figure 152. Control installation made of packing case—used on low flat terrain with no obstructions to visibility.

182. PERSONNEL ACCOMMODATIONS. Where existing shelter is inadequate, tentage is provided for first-stage operation. As improvements are made (figs. 155 and 156), theater of operations or native type housing is constructed. Personnel housing is dispersed, but officers and men of each squad-

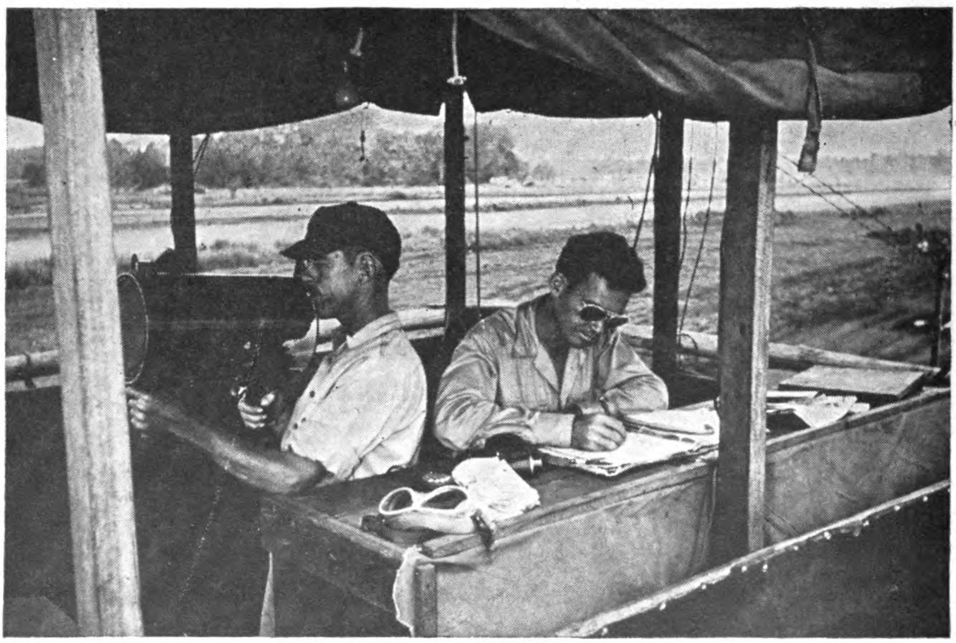


Figure 153. Control tower in operation. Note traffic control lamp.

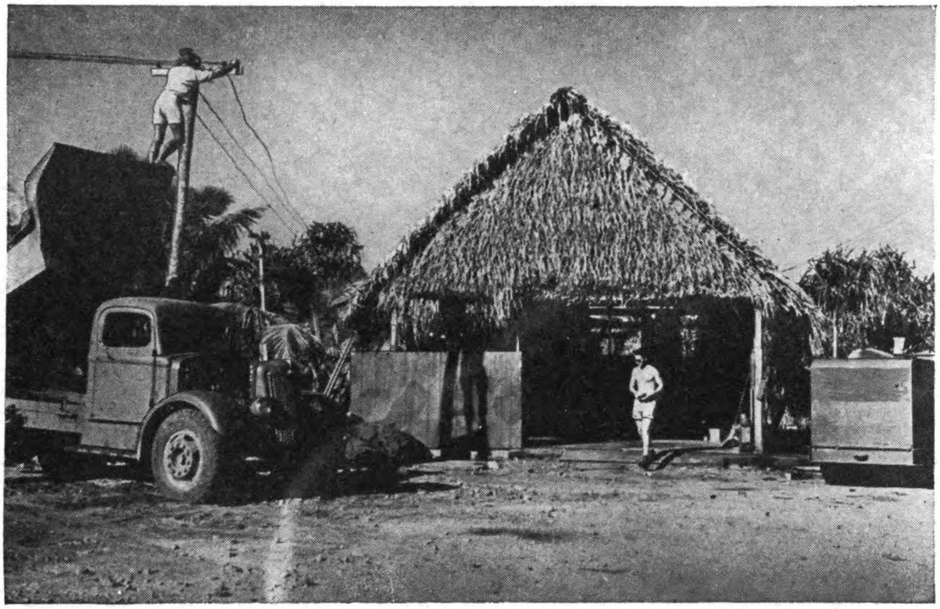


Figure 154. Native type construction to house communications center.

ron are accommodated in a single area. Camps normally are located from ½ to 4 miles from the landing strips. (See app. I for number of persons comprising various Army Air Forces units.)

183. UTILITIES. a. General. Lay-out of water lines, electric power lines, and of telephone, public address, and warning lines is as simple as pos-

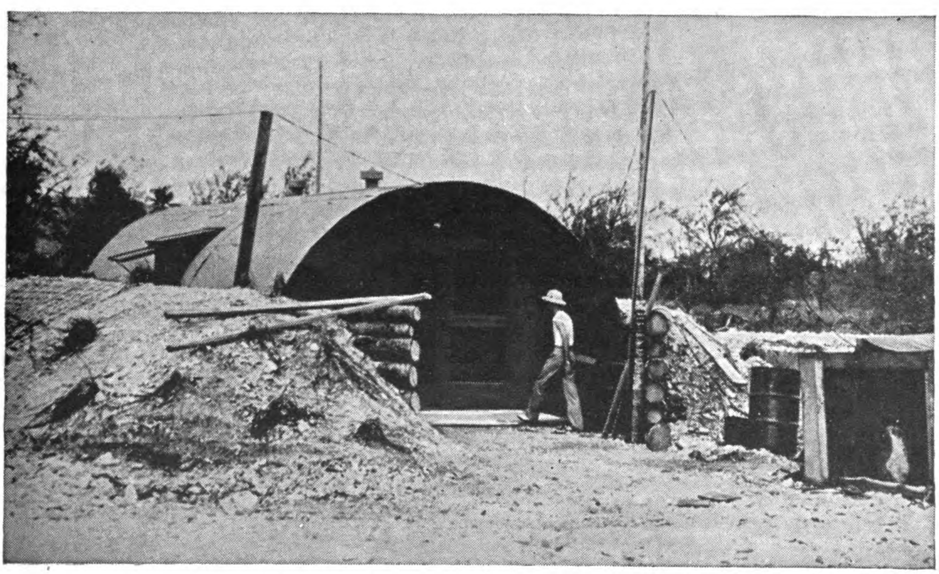


Figure 155. Theater of operations type personnel housing.

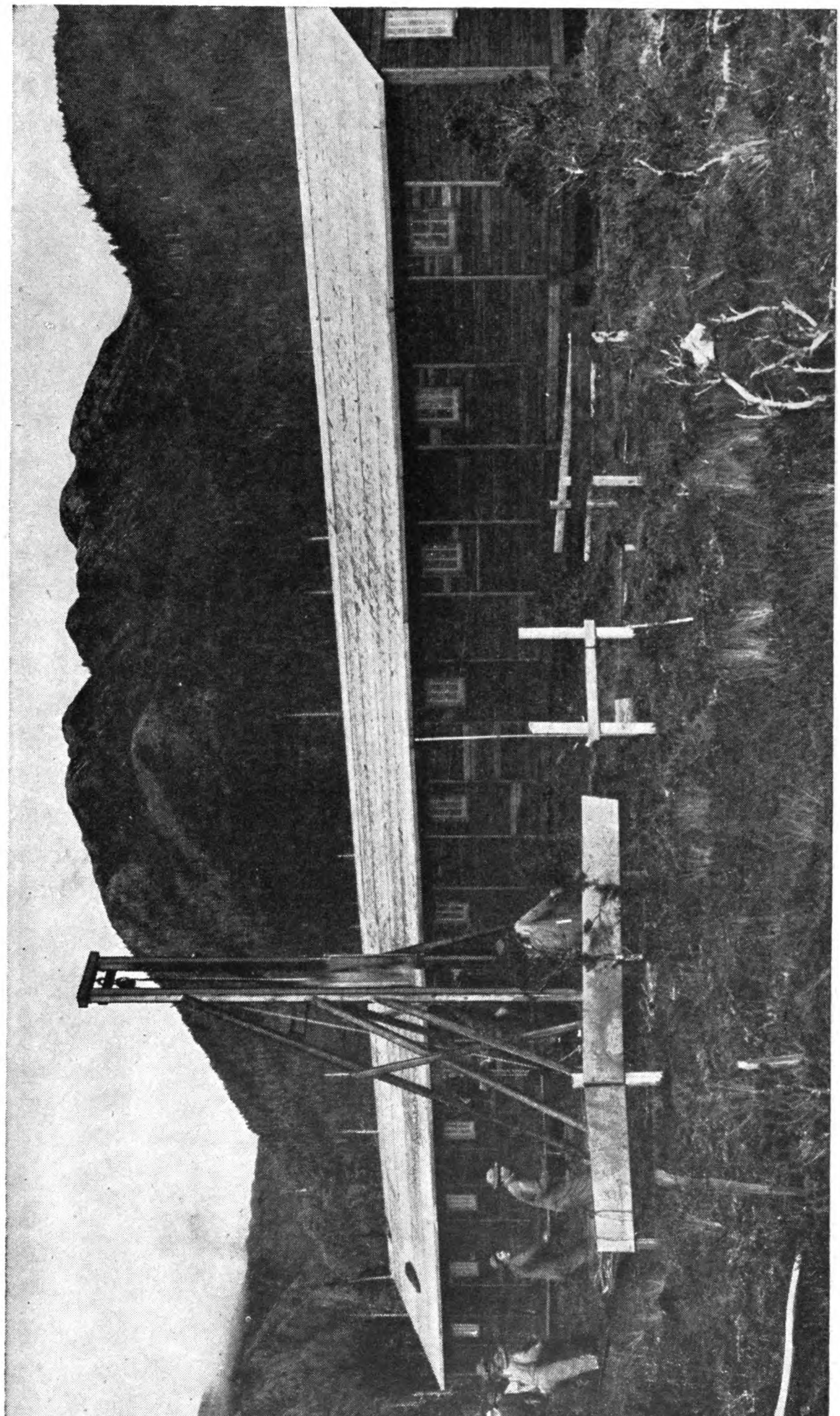


Figure 156. Theater of operations type personnel housing under construction.

Figure 157. Water supply from spring.

sible. To prevent freezing of water lines in cold climates, special measures may be required such as burying, special surface covering, or a pipe lay-out providing continuous circulation of water.

b. Water supply. (1) Personnel water requirements are given in table XLVIII. Initial supply from streams, lakes, springs, wells, existing systems, or any other available source is obtained, purified, and stored, using organic equipment (TM 5–295) (figs. 157 and 158). Water is transported from storage to using units by water cans or tanks on trucks. As an airdrome is enlarged and more equipment becomes available, water-supply facilities may be improved to include increased capacity for treating and storing and a pressure distribution system to using units (fig. 159). Pressure for distribution may be provided by pumping, gravity, or a combination of the two.

(2) Water requirements for construction are estimated as explained in paragraph 172. Water is obtained from any available source with organic pumping and transporting equipment (ch. 25 and table LXXVIII).

c. Electrical supply. The portable, electric-generating equipment sets are the main source of power. A supplemental power supply may be made

Figure 158. Water supply from stream.

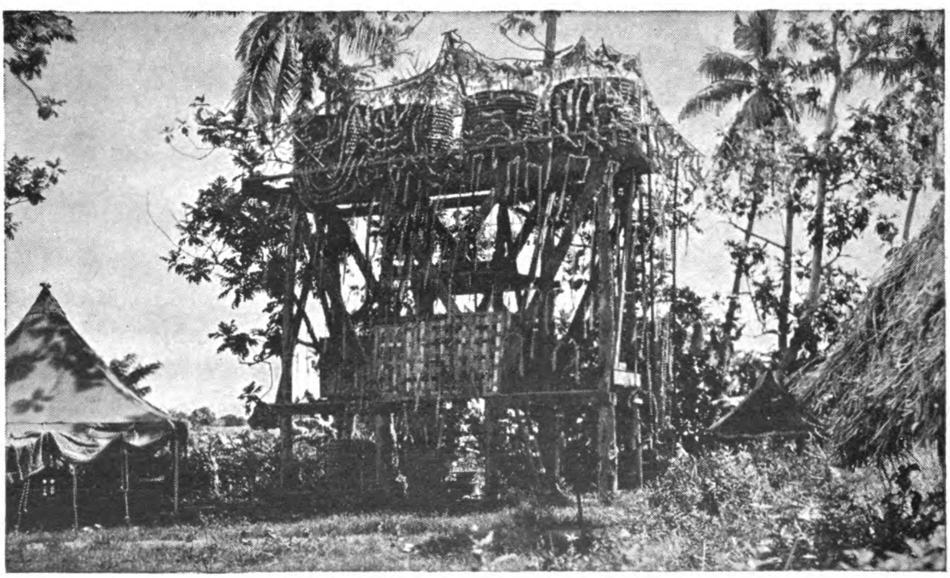


Figure 159. Elevated water tanks with chlorinating unit on intermediate stage.

available from an existing transmission line through a transformer bank and distribution system. However, principal reliance for essential power is on the portable generating equipment so failure of the transmission-line supply will not jeopardize airdrome operations. See TM 1–455 for explanation of electrical equipment and distribution. Electrical wiring plans are shown in TM 5–280. Electric, gas, and kerosene lanterns also may be used for illumination.

d. Sewage disposal. (1) Sewage disposal ordinarily is provided by pit latrines (FM 21–10). Where a piped water supply is available and a water-borne sewage disposal system is required, provision must be made for disposal in accordance with sanitary requirements. Under some conditions raw sewage may be discharged safely into streams, lakes, or estuaries. Natural purification processes are active in all waters but these can be overtaxed if the sewage load is too heavy, that is, if there is insufficient dilution. As a general guide for sparsely settled areas, raw sewage may be discharged safely into streams having a minimum flow of 6 cubic feet per second per 1,000 of sewage-contributing population. Higher dilution is required in more settled areas. Wherever proper dilution is not available for raw sewage, other disposal methods or some form of treatment must be employed. Leaching cesspools with sub-surface irrigation of effluent serve isolated buildings or small groups. Septic tanks are used for larger groups. See TM 5–280, file T.O. 11.33 for typical design of septic tanks to serve groups of 100 to 450 men. For large installations special designs are required. Existing sewerage installations and sewage disposal plants are used wherever possible.

(2) Facilities for sewage disposal always are located and arranged to avoid any contamination of surface or ground-water supply or ground areas used by troops.

184. AIR DEPOT GROUP FACILITIES. Construction required for maintenance and repair operations carried on by the air depot group is similar to that required by a combat group. The principal need of the air depot group is for warehouses, repair shops, repair hangars, administration buildings, hospital wards, and various types of simple structure such as grease racks, incinerators, and tools sheds.

CHAPTER 23

PROTECTION

185. DEFENSE OF AIRDROMES. a. Types of attack. The enemy may attack an airdrome by—

(1) Bombing and strafing.
(2) Dropping parachute troops.
(3) Landing airborne troops.
(4) Ground assault.
(5) Dropping toxic and incendiary agents.
(6) Sabotage.
(7) Any combination of the above.

b. Troops available. To repel attack during operation of the airdrome, the airdrome commander has available the following personnel and their organic arms:

(1) Construction and maintenance personnel such as aviation engineer units.
(2) Ground force units assigned to the airdrome for local defense.
(3) Mobile reserves from adjacent ground force units assigned to support two or more airdromes.

c. Plans for defense. Organization for defense of an airdrome is the responsibility of the airdrome commander, who may appoint a ground defense officer. The officer designated prepares ground defense plans which are coordinated with the plans for air defense. Depending upon the time and personnel available, the defense plan varies from general oral instructions to a detailed written plan. In every case it covers the following points:

(1) OBSERVATION, ALARM, AND COMMUNICATIONS SYSTEM. (*a*) Local enemy aircraft observation must be independent of, but coordinated with, the aircraft warning service and the antiaircraft artillery intelligence service. The same sentinels may, however, be used to warn of chemical attack and to act as spotters in case of an airborne attack.

(*b*) The alarm must be *loud* and *clear* enough to be understood readily and to be heard by men working with noisy equipment such as tractor-dozers, and graders. Sirens and loudspeaker systems have been used with good effect.

(*c*) The communications system takes advantage of all organically assigned equipment and provides for rapid transmission of messages should normal methods break down.

(2) CAMOUFLAGE AND DISPERSION. Every available means is taken to conceal or disguise vital installations. (See par. 188.) Targets are dispersed to offer unremunerative objectives for enemy aircraft and artillery.

(3) ORGANIZATION OF THE GROUND. The defense of an airdrome introduces no new principals in organization of the ground. Some areas may not be available for the construction of fortifications, however, because of operational requirements. Terrain surrounding the airdrome is studied carefully to determine where airborne troops can land and what avenues of approach are open to attacking ground forces. The ground is then organized to deny probable landing areas and routes of approach. This is accomplished by fire from fixed defended localities, by obstacles, and by the use of mobile striking parties. The bulk of the troops should be kept away from probable bombing targets.

(4) ACTIVE DEFENSE. To meet airborne attacks an aggressive, active defense is necessary. A defense tied down to fixed defensive positions will not be successful. Highly mobile local reserves are necessary. These reserves attempt to strike the landing troops before they can organize, to prevent them from collecting their equipment and from forming into effective fighting groups.

(5) ASSIGNMENT OF PERSONNEL. Personnel are assigned to assembly areas for combat or for shelter.

(6) DAMAGE CONTROL. Dispersion and protective construction are passive means of damage control. In addition, crews must, as far as possible, repair damage as it occurs. Detailed fire plans and efficient fire-fighting squads are organized and trained to operate in conjunction with the fire-fighting platoon (par. 194).

(7) DEFENSE AGAINST CHEMICAL ATTACK. At all times gas masks are carried or kept immediately at hand. Personnel may be issued protective clothing. Decontamination squads are organized and trained to operate in conjunction with chemical decontamination units.

(8) IMMOBILIZATION OF VEHICLES NOT USED BY DEFENDERS. All vehicles not used in the defense are dispersed and concealed. Plans are made for quick and uniform destruction of all vehicles not evacuated in a withdrawal.

(9) LIAISON WITH NEARBY FRIENDLY TROOPS. Defense plans are coordinated with those of all friendly units in the area, and close liaison is maintained during any operation.

(10) DEMOLITION TO PREVENT SEIZURE AND USE OF AIRDROME BY HOSTILE FORCES. See paragraph 187.

d. References. For other information on defense refer to FM 5–6 and FM 100–15.

186. LOCAL SECURITY OF CONSTRUCTION TROOPS. a. The commander of construction units is responsible for the local security of his troops at all times. If security detachments from ground troops provide local security during construction, the construction units are assigned supplementary missions and areas to defend. Aviation engineers often must operate in isolated localities without protection by security detachments of other arms. In such cases the construction unit commander must provide for all-around defense of the site utilizing the troops under his command and their organic weapons, which include the rifle, carbine, caliber .50 machine gun, submachine gun, rocket launcher, 60-mm mortar, pistol, and multiple-gun motor carriage. Plans for the defense cover the points discussed in paragraph 185c.

b. Operators of heavy equipment may be protected from strafing and sniper fire by armored cabs obtained from depots or improvised. Standard armored cabs are issued as Class IV equipment. Where cabs must be improvised, the following basic requirements should be considered:

(1) Steel plate must be at least ½ inch thick, armor plate being preferred to mild steel, or two layers of thinner plate can be used with at least a 3-inch air space between them.

(2) For greatest protection, both size and number of openings for vision, ventilation, and exit should be kept to a minimum.

(3) A tractor with a well-protected but blinded operator is of little use. There must be a balance between protection and vision. Usually there must be several sizes of vision slits or ports. The required size may be reduced by locating the slit as close to the operator's eyes as practicable.

(4) In tropical climates or deserts the steel inclosures become unbearably hot unless properly ventilated. Several ports are required to allow circulation of air, and a fan for forced circulation is desirable. In addition, a shade or canopy should be provided to keep the direct rays of the sun from the steel plates. The canopy should be at least 18 inches above the roof and extend 3 feet over the sides.

(5) To provide for quick exit two doors or openings are needed. For complete protection in forward areas all openings through which hand grenades may be thrown should be covered with some form of screen.

(6) Overlapping construction should be used at joints to prevent small particles called bullet splash from entering small cracks.

(7) For knock-down purposes a combination of bolted and welded construction is preferred. Where bolts are used the nuts should be welded to the cab on the inside so if the head of the bolt is sheared off by a projectile, the nut will not fly around inside the cab and act as a secondary projectile.

(8) The inside of the cab should be painted white to improve interior visibility.

(9) Sponge rubber pads should be provided on the inside to protect the operator from bumps when his eyes are close to the vision slit.

c. Material for improvised cabs may be obtained from such sources as wrecked tanks and landing barges.

187. DEMOLITION OF AIRDROMES. a. Scope. The complete destruction of an airdrome is a major project requiring considerable time, labor, and planning. The airdrome commander decides when and how destruction will be effected.

b. Plan. A plan for demolition is made during the design and original construction period. As improvements are made the plan is amended and enlarged to keep it up to date. Plans to deny use of adjacent areas on which enemy aircraft can land also must be provided. Priorities are assigned each item to be destroyed, the most vital installations and equipment being first. The plan also includes a schedule assigning personnel to specific demolition tasks.

c. Methods of demolition. (1) RUNWAYS AND TAXIWAYS. These are most difficult to destroy effectively. Explosives may be placed in culverts. Extra culverts for the specific purpose of receiving charges may be placed during construction. They may be metal or simple wood-box type, placed 2 to 3 feet underground and sloped to drain. If time is available, charges may be placed as for cratering roads. Mechanical earth augers, if available, may be used for boring holes. Time bombs may be buried by the same method. Also, depending upon time left after friendly aircraft have been evacuated, heavy earth-moving equipment may be used to construct ditches or to plow and tear up landing areas.

(2) BUILDINGS AND STORAGE AREAS. These may be destroyed by explosives or by fire aided by gasoline.

(3) VITAL INSTALLATIONS AND EQUIPMENT. These can be demolished by explosives, fire, or hand smashing.

d. Mines and booby traps. Antitank and antipersonnel mines and booby traps are placed throughout the area if time is available (FM 5–31).

188. CAMOUFLAGE. a. General. Camouflage is deception. Its main purposes are to increase the effectiveness of operations and enhance the security of our own troops and to decrease the effectiveness of the enemy's effort. Lack of time and material generally makes complete camouflage of an entire airdrome impractical, resulting in reliance upon dispersion and concealment of vital installations and our own aerial superiority for protection against enemy aerial observation and attack. Except for concealment of vital installations, general camouflage ordinarily is second- and third-stage work at field airdromes. (See par. 52.)

b. Plans. The camouflage plan is the responsibility of the airdrome commander who may appoint a camouflage officer to devise and put it into operation. The plan is formulated during reconnaissance and design, and extended during construction of the airdrome. The camouflage section assists in supervising construction and maintaining camouflage discipline in bivouac areas and around such vital installations as radar, bomb-, and gasoline-storage areas, and antiaircraft artillery positions.

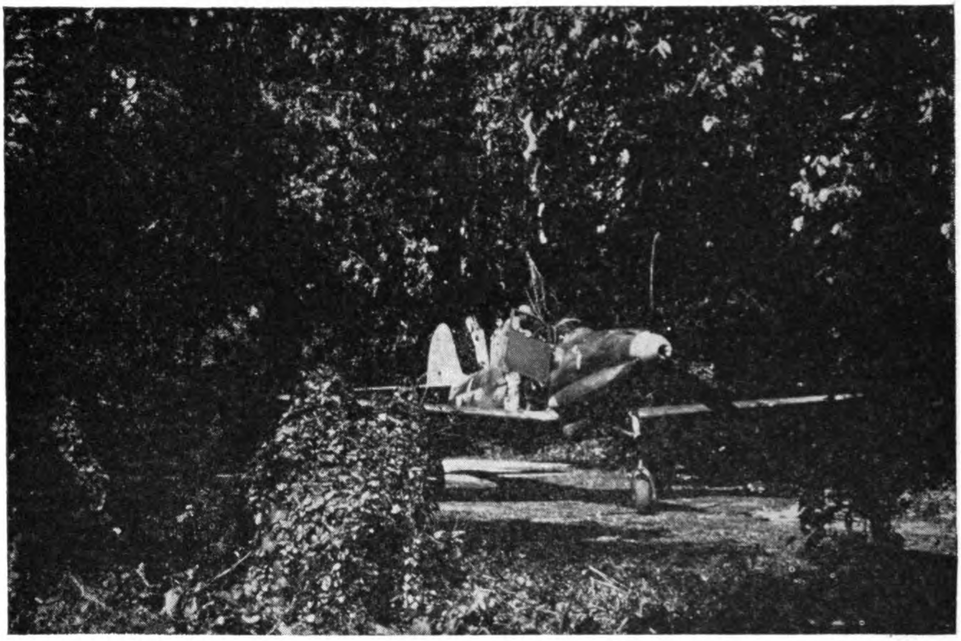


Figure 160. Plane naturally concealed at hard standing

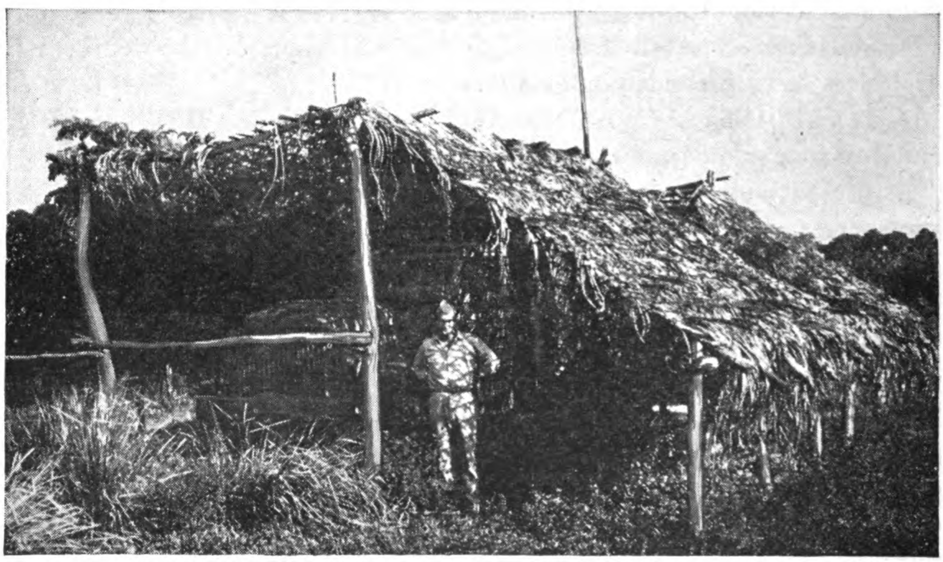


Figure 161. Vehicle concealed by construction of natural materials.

c. Methods. (1) Siting is the primary consideration in the application of camouflage and is accomplished by effective reconnaissance. Siting involves relation to terrain or ground-pattern blending; lay-out with respect to operation, access, and traffic control; and retention of existing materials.
(2) Dispersion combined with proper concealment is depended upon to provide effective protection from enemy attack (fig. 160). Factors which influ-

Figure 162. Artificial cover used to supplement natural cover.

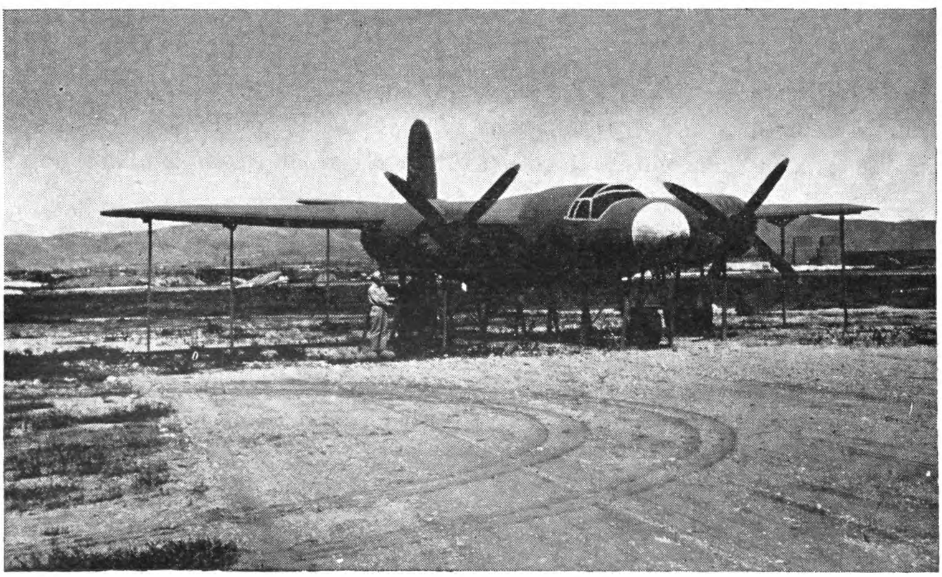


Figure 163. Decoy airplane.

ence dispersion are site conditions, operations, and locations of such installations as runways, hard standings, and access roads.

(3) Camouflage discipline of personnel is important and must be stressed throughout operations.

(4) Concealment by artificial means (fig. 161) is used only after full advantage has been taken of siting, dispersion, and natural materials (fig. 162).

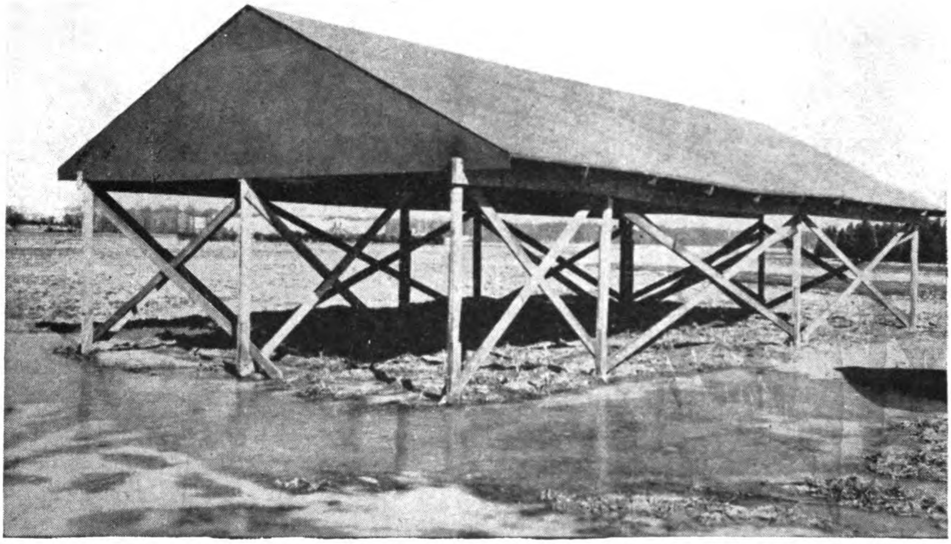


Figure 164. Decoy building.

(5) Operational deception involves the use of decoys to mislead the enemy, ranging from small decoy installations such as aircraft (fig. 163), buildings (fig. 164), guns, and emplacements, to decoy airdromes complete with false facilities.

d. References. For detailed information on camouflage see FM 5–20; FM 5–20, supplement 6 (when published) ; and TM 5–267 and supplements.

189. ENTRENCHMENTS. a. Types. When the engineer construction unit first arrives on the airdrome site simple entrenchments are provided for personnel and for weapons. These protect personnel during air raids and provide ground organization for active defense against attack. Typical construction includes the following:

(1) Prone shelters (fig. 165) are 2 feet deep, not more than 2 feet wide, and long enough to permit the occupant to lie prone. These shelters are dug rapidly and take advantage of natural cover. They furnish protection from small-arms fire and bomb fragments. Suitable for shelter during attacks by bombardment and strafing airplanes, they are not deep enough to protect against the crushing action of tanks.

(2) Fox holes (figs. 166 and 167) may be built for one man or for two men. Fox holes have a fire step, thus allowing the occupants to return fire.

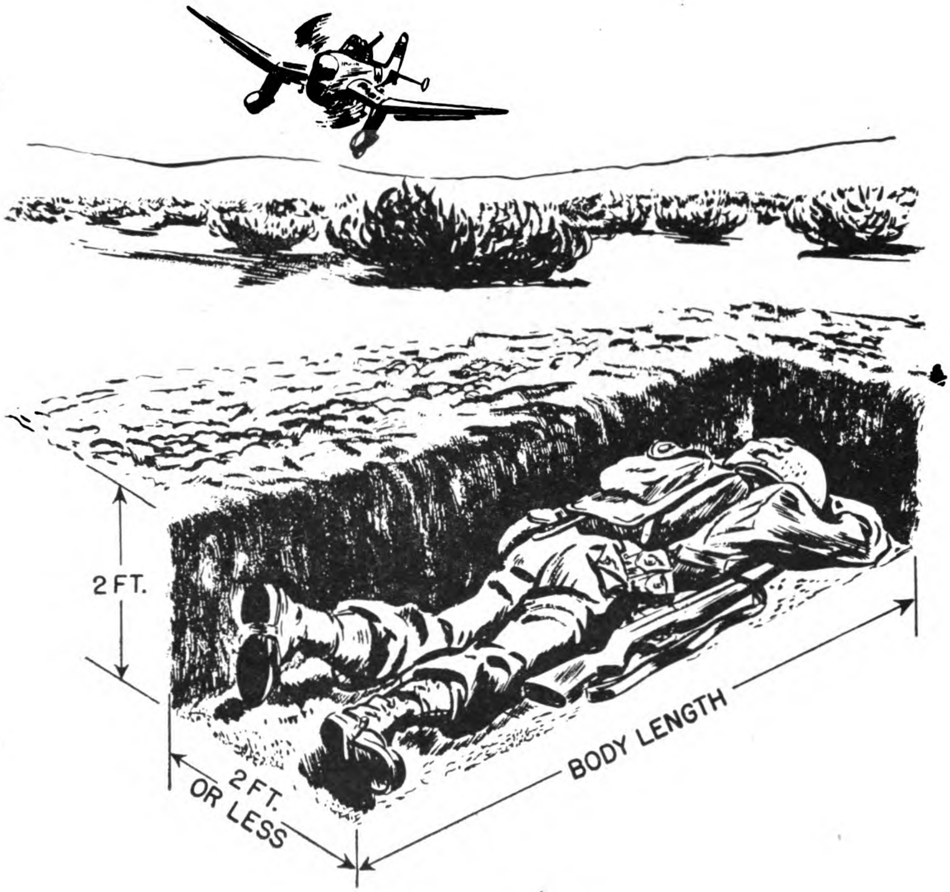


Figure 165. Prone shelter.

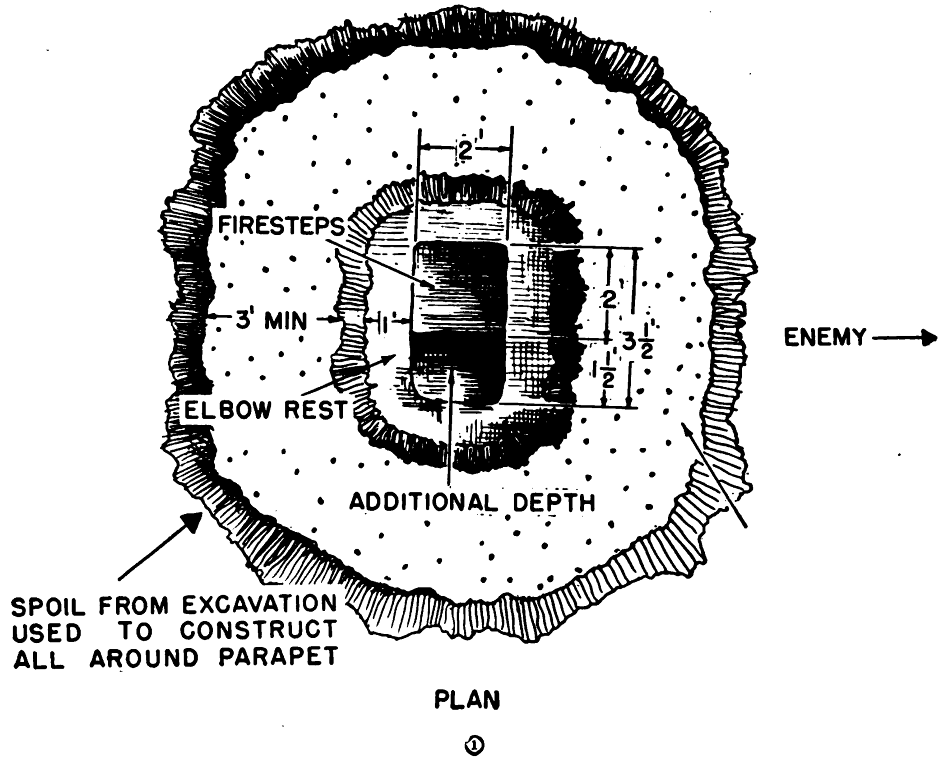
(3) Observation posts (fig. 168) may be nothing more than well-concealed fox holes. Observation posts are necessary for an effective alert system. Excellent lookout posts may be constructed in trees.

b. Terrain features. Advantage is taken of all terrain features, which may be used in their natural state to provide concealment and protection, or converted into protective structures.

c. Camouflage of entrenchments. Concealment and dispersion must be planned from the first. In areas which are to be excavated and filled all turf, sod, leaves, and forest humus are removed, set aside, and replaced after construction (fig. 169). Spoil is not placed indiscriminately on parapets or adjacent to structures but is disposed of inconspicuously. Fresh spoil is covered. Fresh spoil and a regular outline together would form a perfect signpost for aerial observers.

d. Digging expedients. Experience has shown the ditching machine to be effective for rapid construction of short sections of trench.

e. Reference. For detailed information on entrenchments, see FM 5–15.



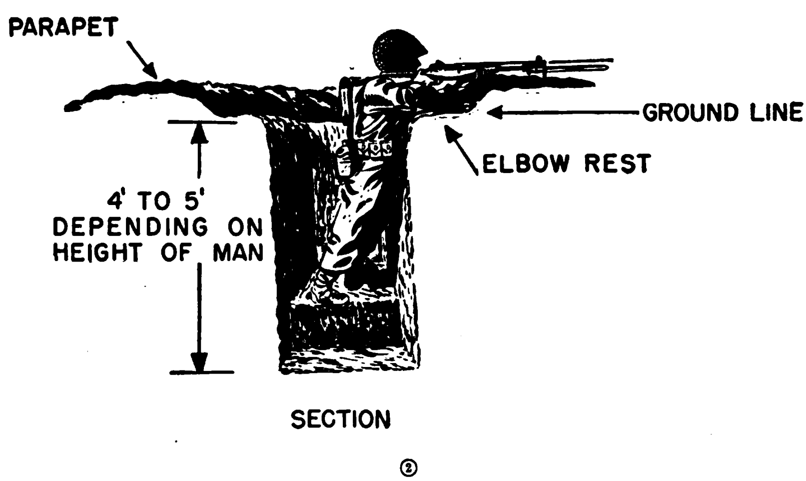


Figure 166. One-man fox hole.

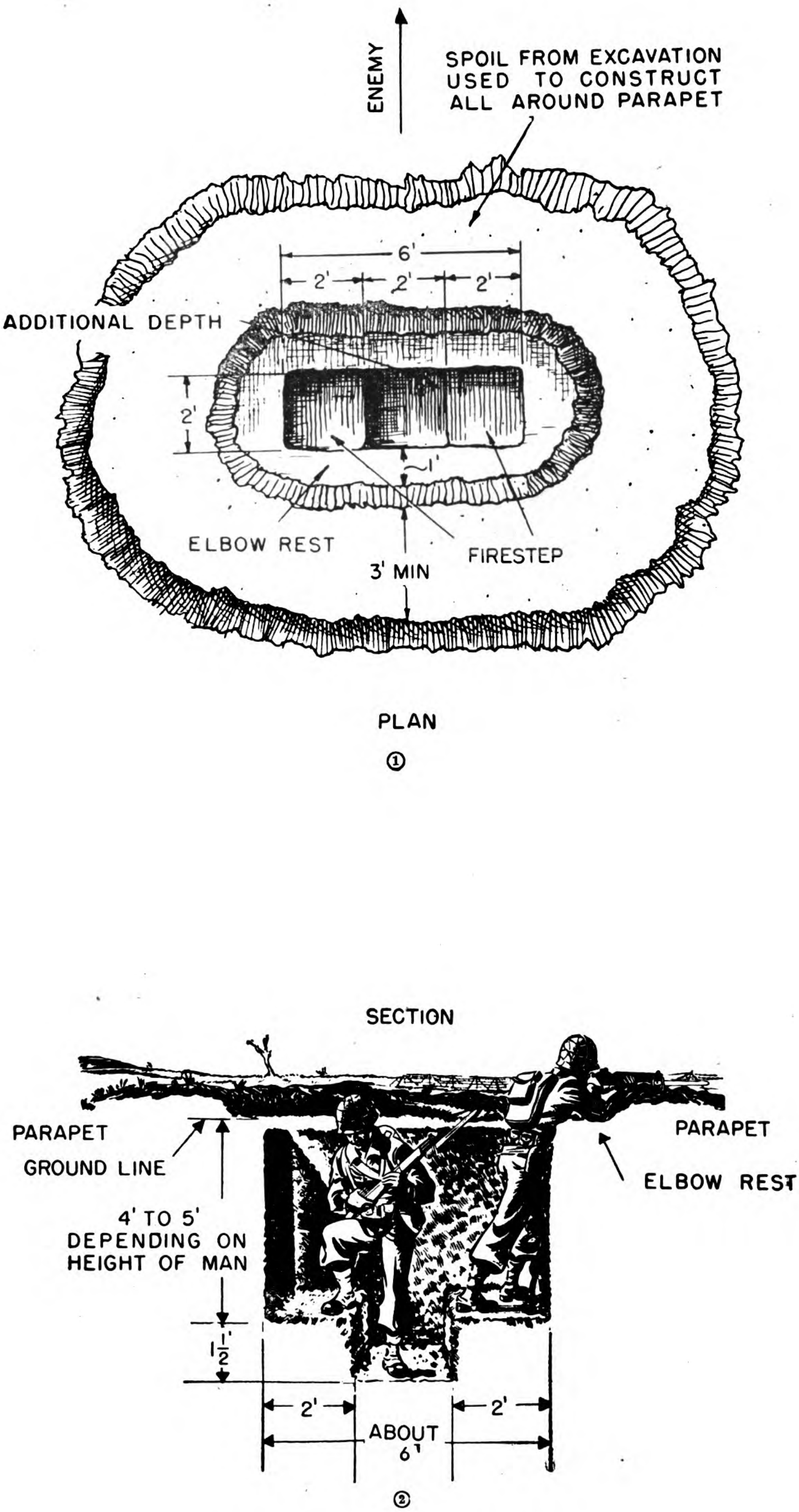


Figure 167. Two-man fox hole.

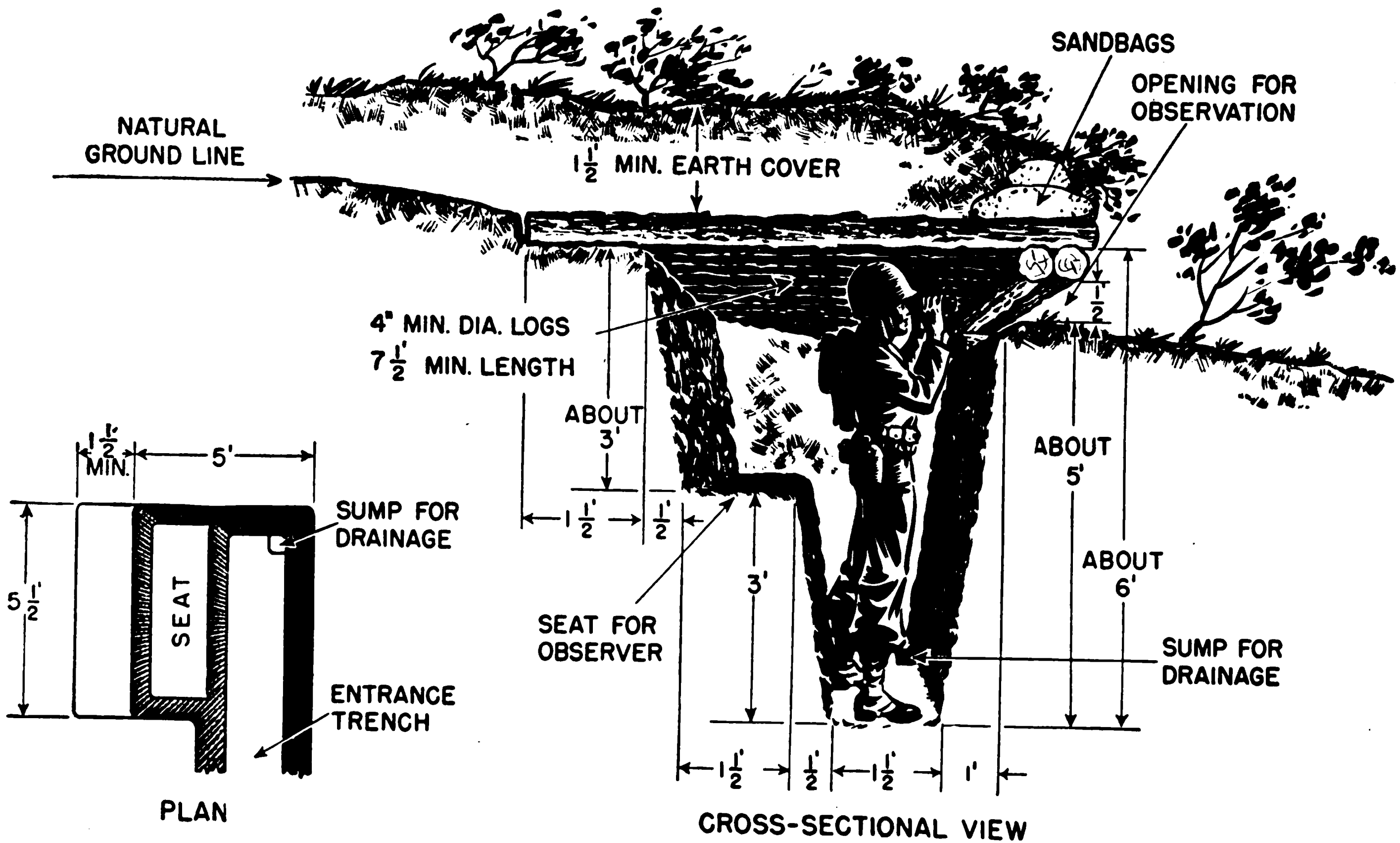


Figure 168. Covered observation post.

Figure 169. Camouflaged fox hole.

190. EMPLACEMENTS. Aviation engineers have the caliber .50 machine gun and the multiple-gun motor carriage. Emplacements for these weapons (figs. 170 and 171) are sited for both ground and aerial targets. Engineer troops may be called upon to prepare antiaircraft artillery installations. These include gun, searchlight and generator, and gun director emplacements (figs. 172, 173, and 174). (For detailed information on emplacements see FM 5–15.)

191. SHELTERS. a. Scope. When work first starts on an airdrome site the entrenchments discussed in paragraph 189 may be sufficient for defense. As the construction nears completion and the airdrome becomes a vital installation, blast- and splinter-resistant construction may be necessary. The prone shelters and fox holes are not abandoned but are used in conjunction with the new construction. Enemy artillery seldom is in position to fire on airdromes. Protective structures for airdromes, therefore, are designed to protect against aerial weapons such as—

(1) Demolition bombs.
(2) Fragmentation bombs.
(3) Incendiary bombs.
(4) Chemical bombs.
(5) Sprayed chemicals.

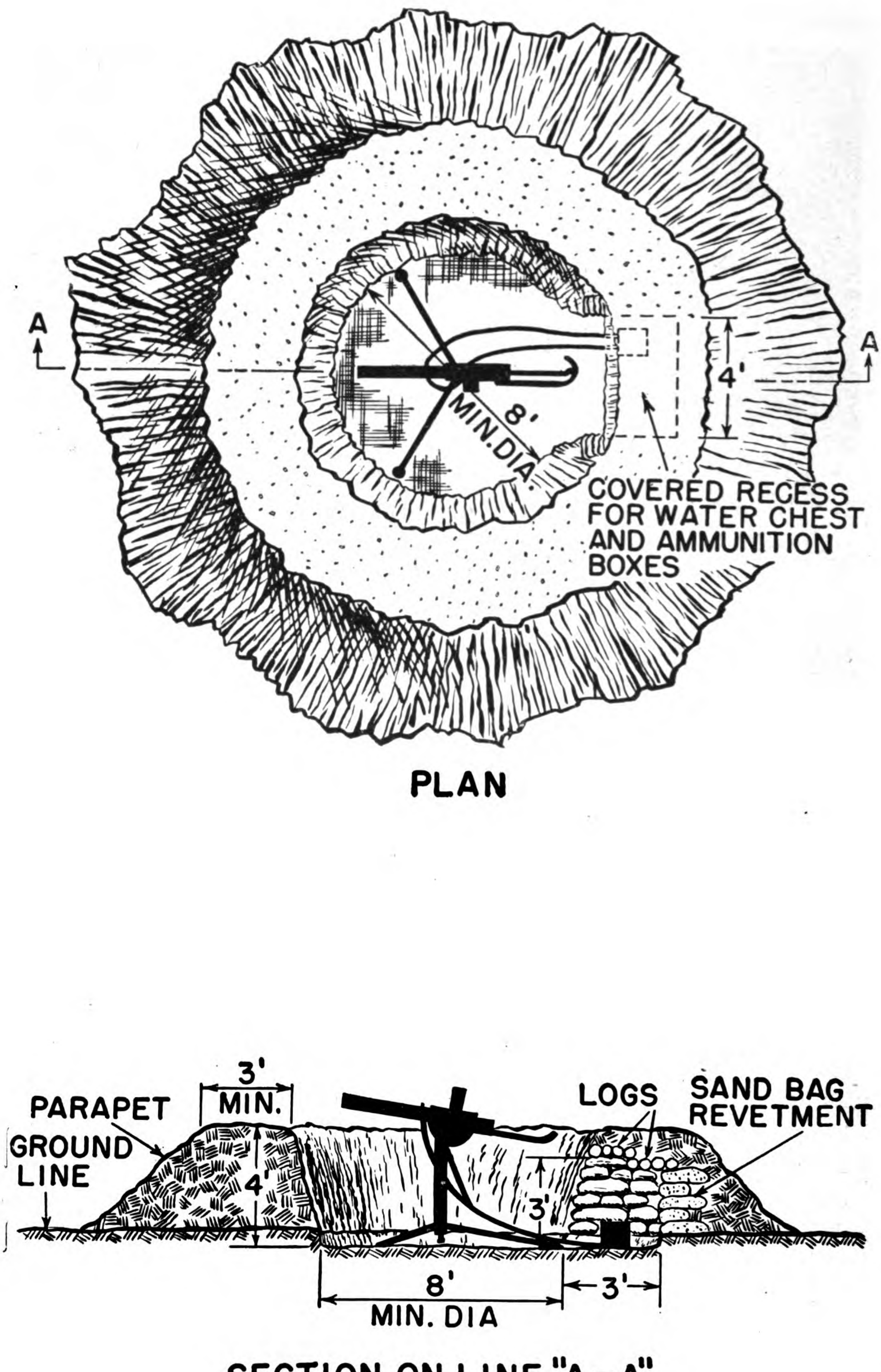


Figure 170. Emplacement for caliber .50 machine gun.

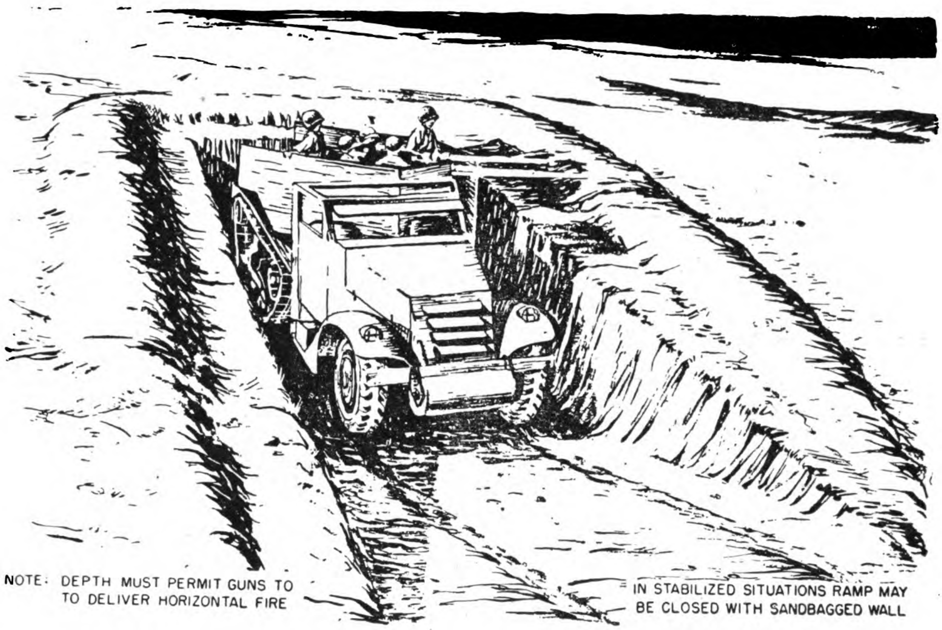


Figure 171. Pit type emplacement for multiple-gun motor carriage.

b. Revetments around existing buildings. Buildings may be protected from blast effect and fragments by protective walls around them. Examples are: earth wall (fig. 183); earth-filled timber walls (fig. 175); and sandbags (fig. 185). Baffle walls are placed in front of openings. To prevent excessive internal pressure in earth-filled walls, a roof should be provided which keeps out rain water.

c. Structural considerations of shelters. Blast- and splintering-resistant structures may be erected completely above ground or partly buried. The forces to be resisted and the degree of protection practicable are the same in either case. General design features applicable to both types follow:

(1) Structures should be dispersed and sited on slopes of hills where possible, with a minimum of 50 feet between adjacent buildings.

(2) Design will be primarily for protection against high-explosive bombs, which produce destructive effects by fragments, blast, and earth shock.

(*a*) Bomb fragments have considerable penetrative power. When a wall has been designed to stop fragments usually it is thick enough to protect against blast. Roofs and floors usually are less exposed to fragments than walls and may be less thick.

(*b*) Blast effect above ground travels as pressure waves, a positive pushing wave follows a negative suction wave. Therefore, walls must be designed for pressure inside and out.

(*c*) Earth shock, which occurs when a bomb is detonated underground, travels in horizontal and vertical waves. If a bomb explodes near an under-

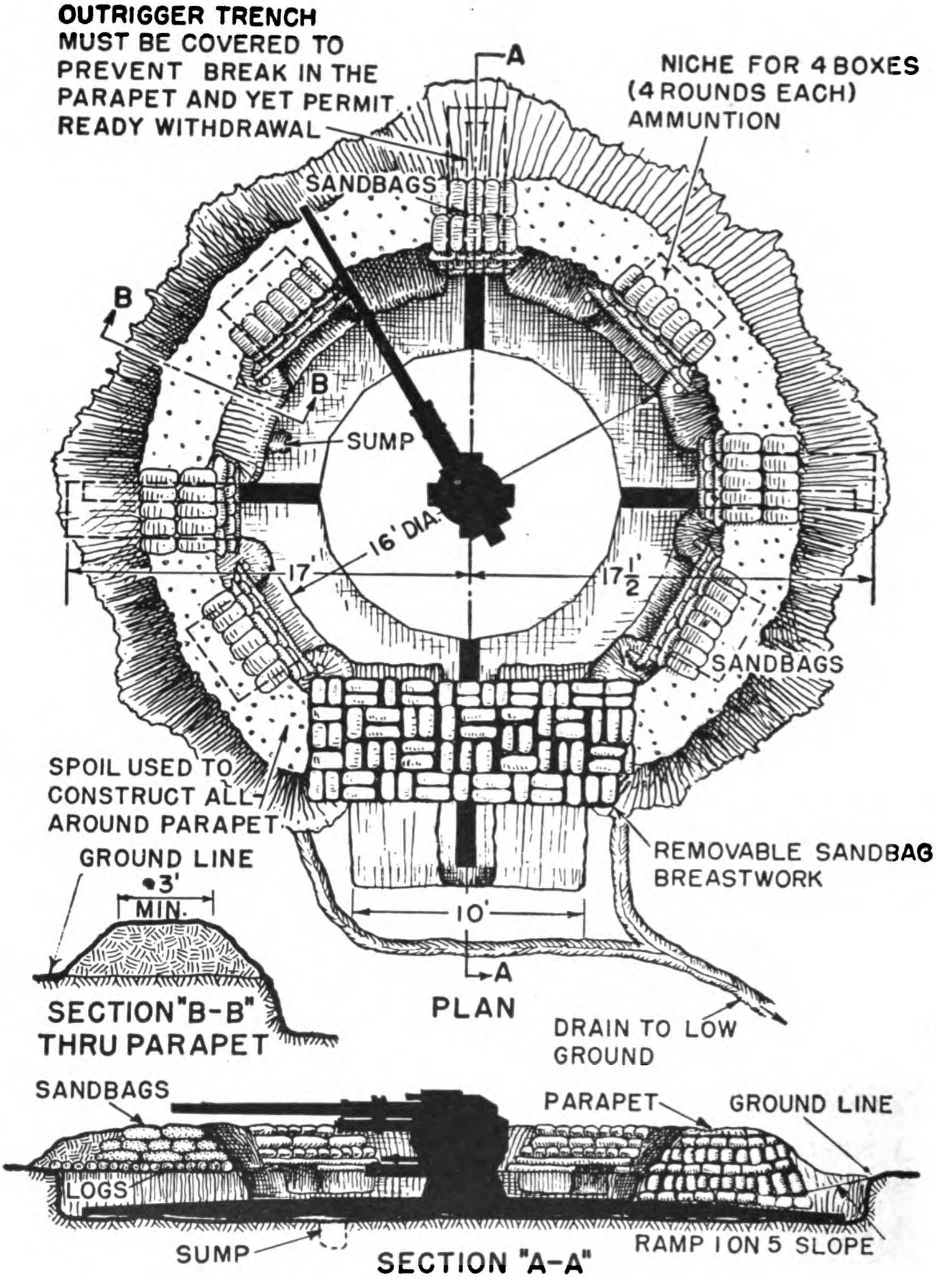


Figure 172. 90-mm antiaircraft gun emplacement.

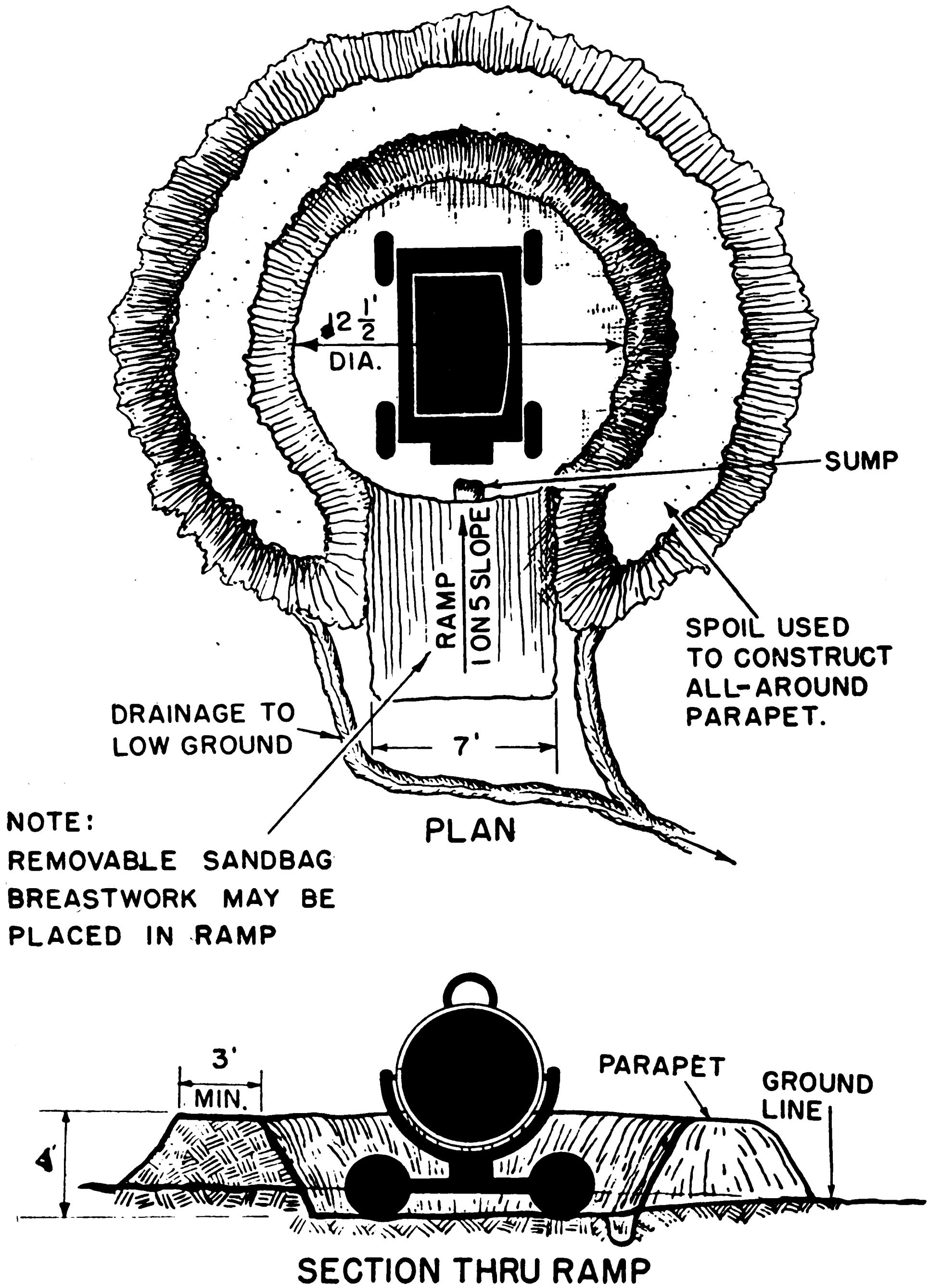


Figure 173. Searchlight emplacement.

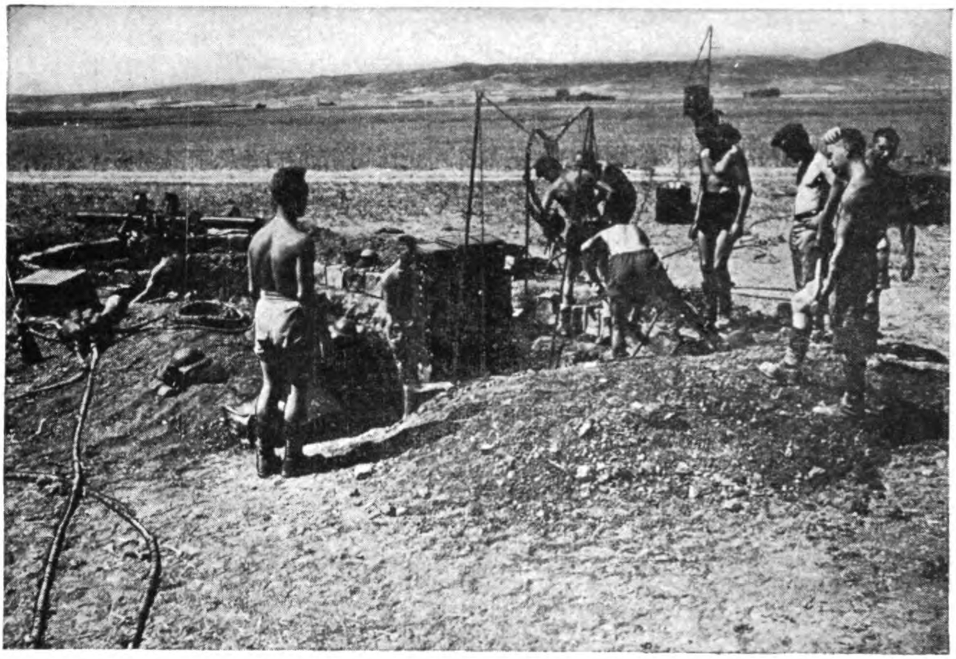


Figure 174. Digging emplacements for range finder and director.

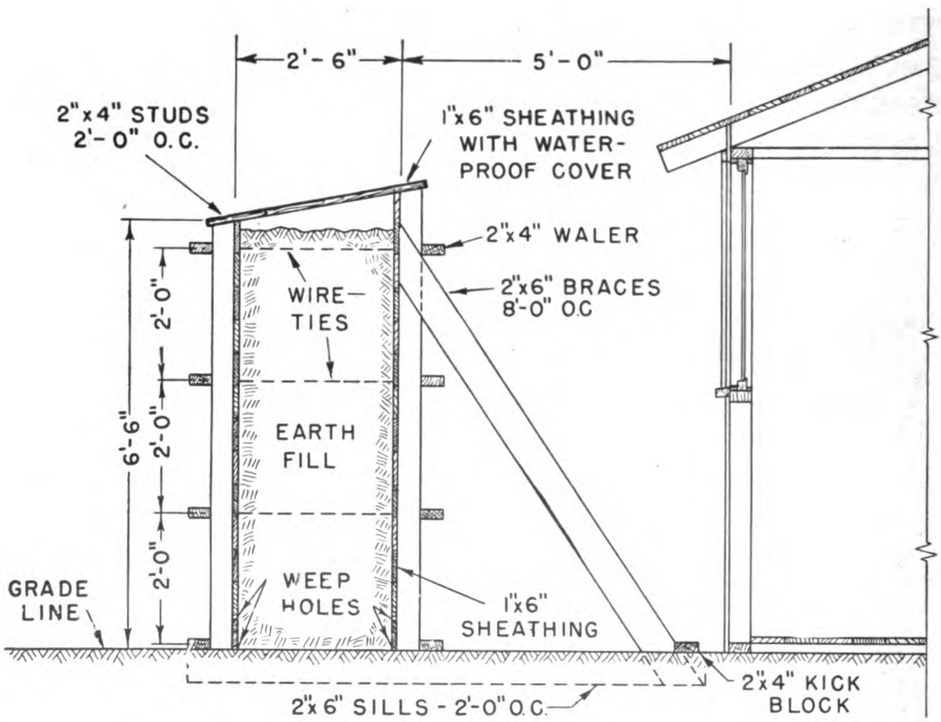


Figure 175. Protective wall for use around buildings. (See fig. 150.)

ground structure, the vertical wave, or earth movement, may reach the shelter before the horizontal wave. The combined effect of the waves is to tip and twist the structure. To prevent collapse it is necessary to fasten floor and roof securely to the walls and to brace the entire structure so it acts as a solid unit or block (fig. 179).

(3) Since bombs larger than 550 pounds normally will not be wasted against a dispersed target, such as an airdrome, usual design is for protection against the 500-pound or 550-pound bomb. Table XXIX shows thickness needed against various bombs and shells.
ranged as in rigid frame construction.

Table XXIX. Thickness of materials required to protect against penetration of fragments from projectiles and bombs exploding at a distance of 50 feet.

Material	Thickness measured in	High-explosive shell			General-purpose bomb			
		75-mm	105-mm	155-mm	100-pound	250-pound	500-pound	1,000-pound
Solid walls:	Inches							
Brick masonry		4	6	8	8	10	13	17
Concrete (plain)		4	5	6	8	11	15	18
Concrete (reinforced)		3	4	5	7	9	12	15
Timber		8	10	14	15	18	24	30
Walls of loose material packed between boards:	Inches							
Brick rubble		9	10	12	18	24	28	30
Gravel, small stones		9	10	12	18	24	28	30
Earth		15	18	24	24	30		
Sandbags filled with:[1]	Inches							
Brick rubble		10	10	20	20	20	30	40
Gravel, small stones		10	10	20	20	20	30	40
Sand		10	10	20	30	30	40	40
Earth		20	20	30	30	40	40	50
Parapets of:[2]	Feet							
Sand (dry)		1	1½	2	2	3	3	4
Earth (dry)		2	3	4	3	4	5	

[1] Figures given in multiples of width or thickness of sandbags.
[2] Figures given to nearest half foot.

(4) Of the materials usually available reinforced concrete is the most efficient protection against military projectiles. Where concrete is not available other materials are substituted. Walls of rigid wooden-frame construction, while not as resistant to splinters as walls of brick load-bearing construction, are more resistant to blast. Corrugated metal shelters are well suited for semi-buried structures. No matter what material is used *the most important design*

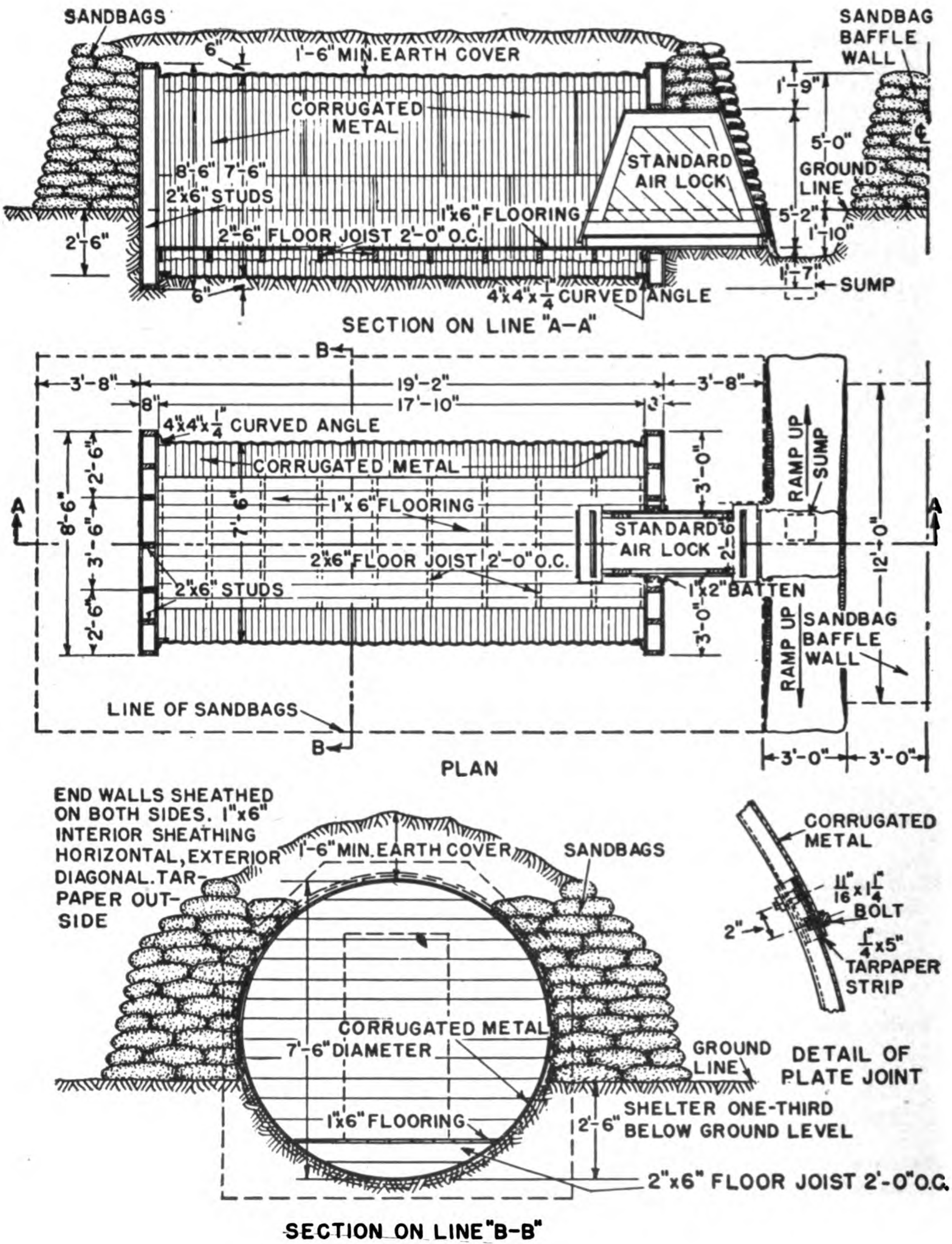


Figure 176. Surface shelter constructed of corrugated metal.

feature is rigidity. In reinforced-concrete construction reinforcing rods should be welded where they lap and at corners and joints the steel should be arranged as in rigid-frame construction.

(5) Entrances are protected by baffle or screening walls to reduce blast pressure and keep fragments from entering. Each structure has at least two exits.

(6) Ventilation for structures not gasproofed usually is obtained by several roof vents. Doors will not provide sufficient ventilation during continued occupance. Gasproofed structures should use the collective protector issued by the Chemical Warfare Service for mechanical ventilation. Table XXX gives minimum ventilation and space requirements for shelters.

Table XXX. Capacities of unventilated shelters.

Type of shelter	Capacity (number of men)	Outside air below 90°F.		Outside air above 90°F.	
		Space—cubic feet per person[1]		Space—cubic feet per person[1]	
		Rest	Normal desk work	Rest	Normal desk work
Underground or above-ground walls of low heat conductivity[2]	10	200	360	240	500
	25	300	540	360	725
	50	400	750	500	1,000
Above-ground walls of high heat conductivity[3]	10	150	270	180	360
	25	235	425	270	540
	50	300	540	380	720

1 Based on occupancy of 3 hours.
2 Walls of wood and dry earth have low heat conductivity.
3 Walls of metal, concrete, masonry, and damp earth have high heat conductivity.

Figure 177. Improvised surface shelter.

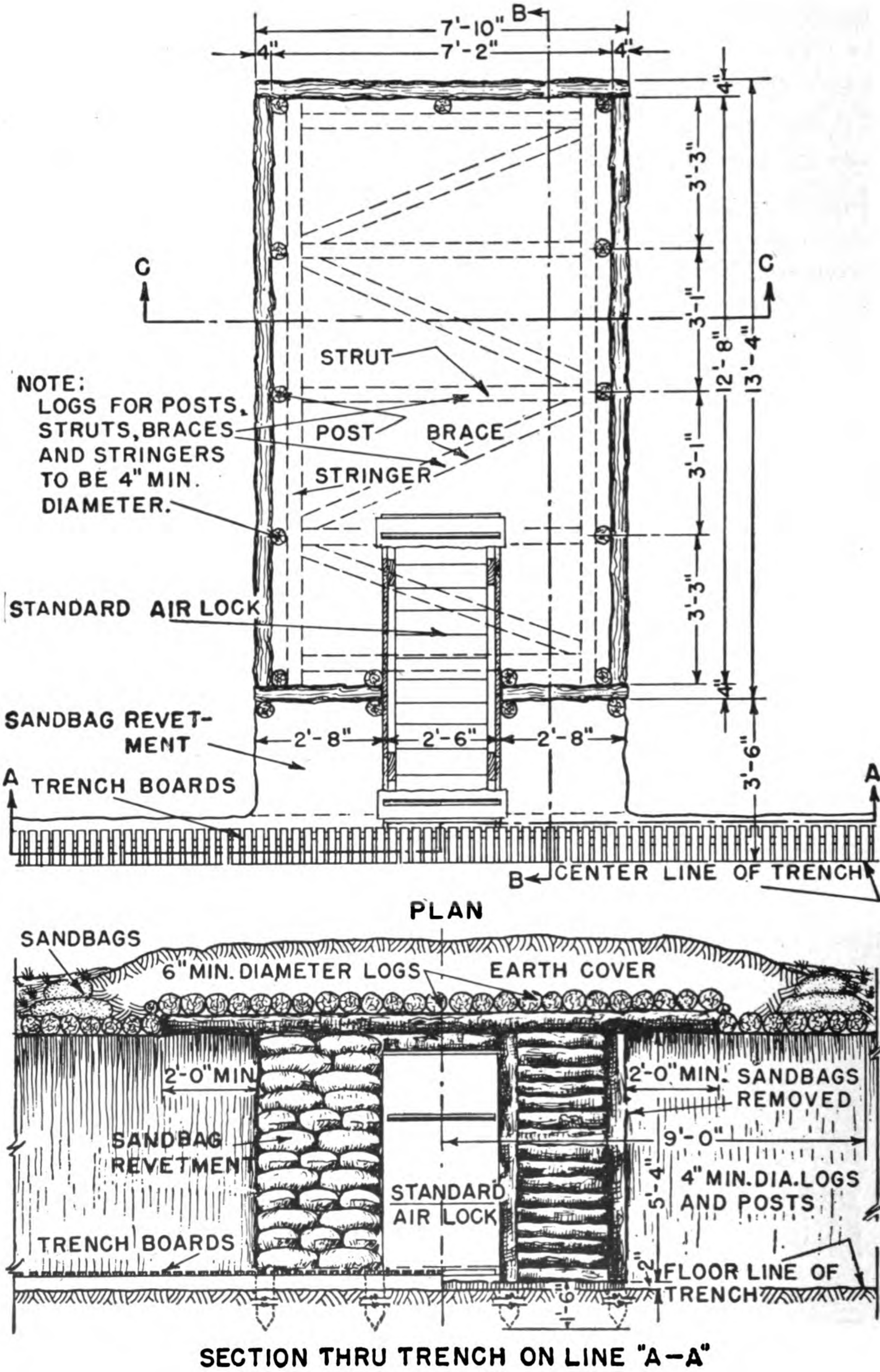


Figure 178. Cut-and-cover shelter constructed of logs.

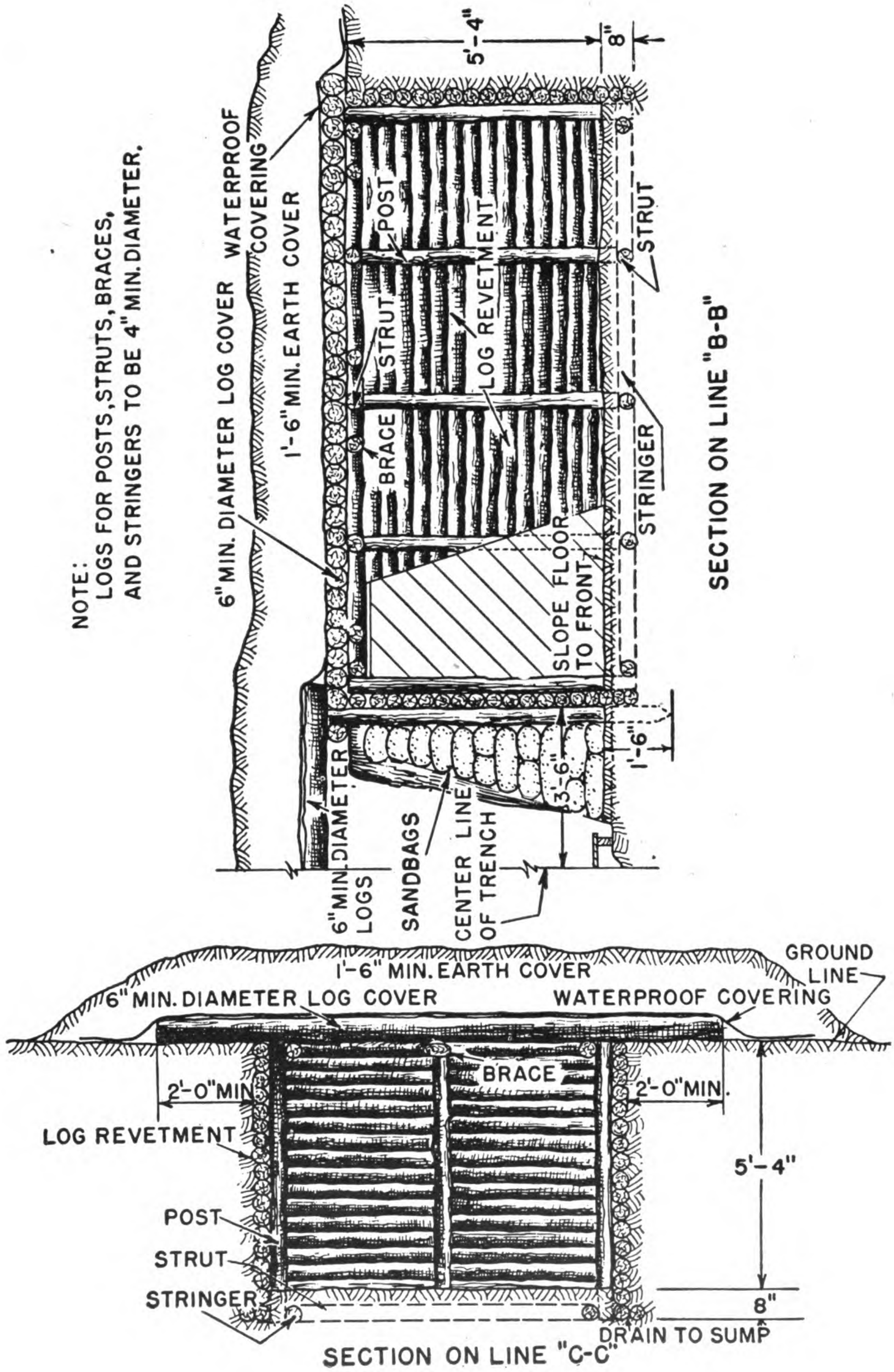


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Figure 178. Continued

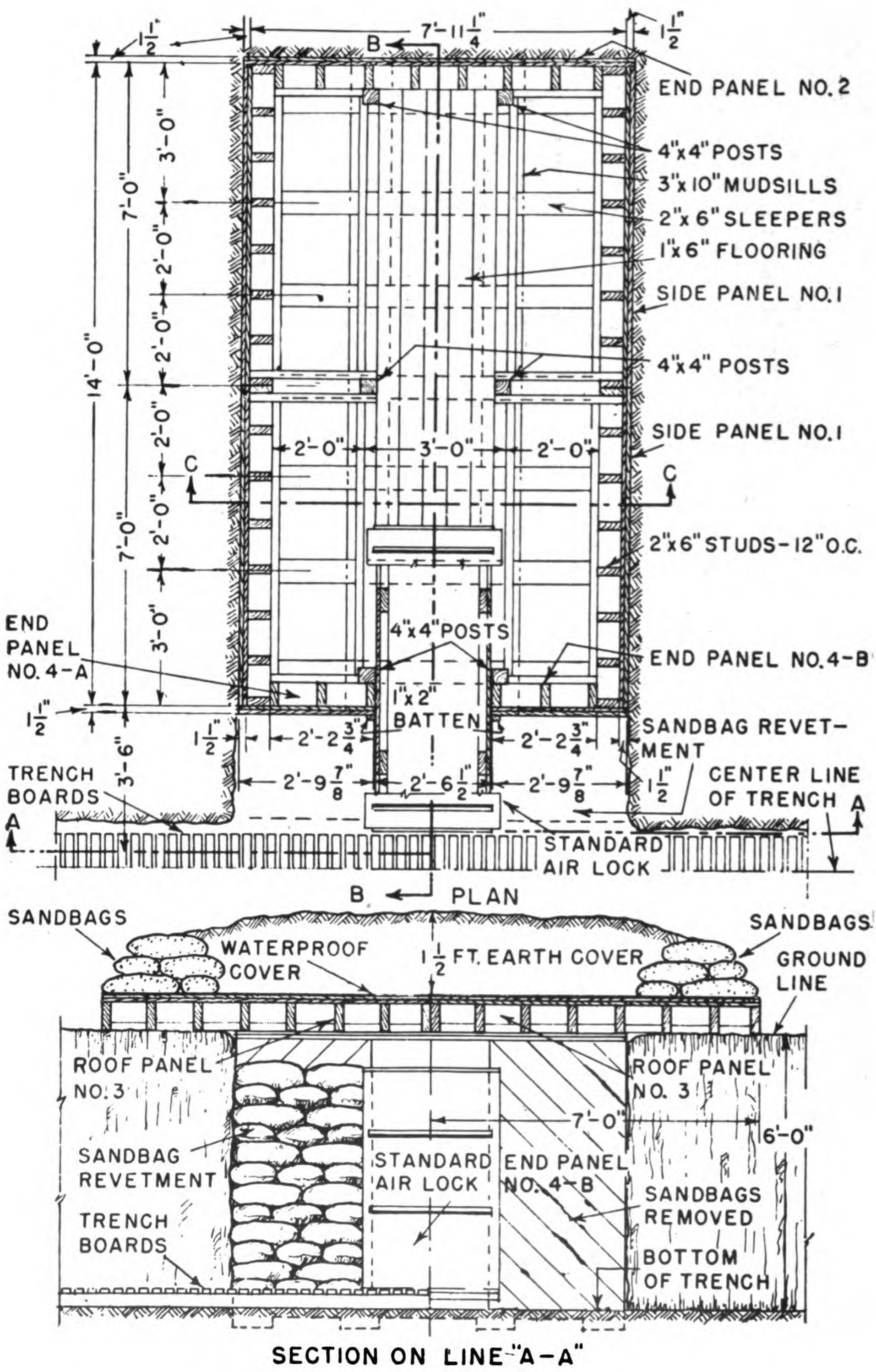
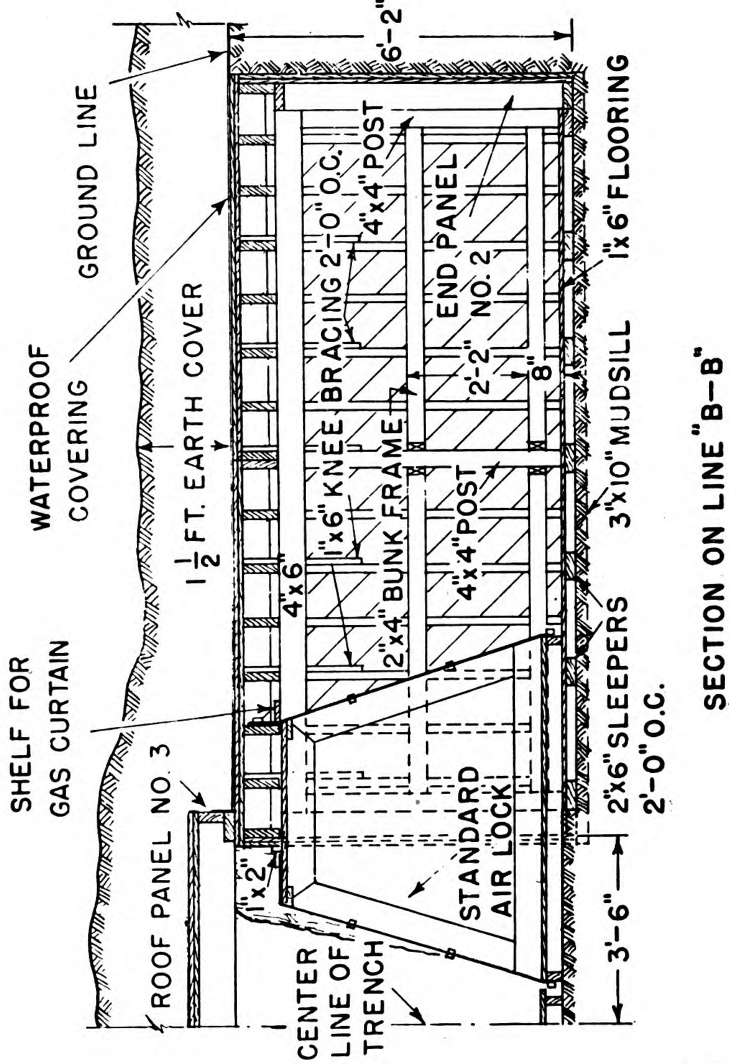


Figure 179. Cut-and-cover shelter constructed of dimension lumber.



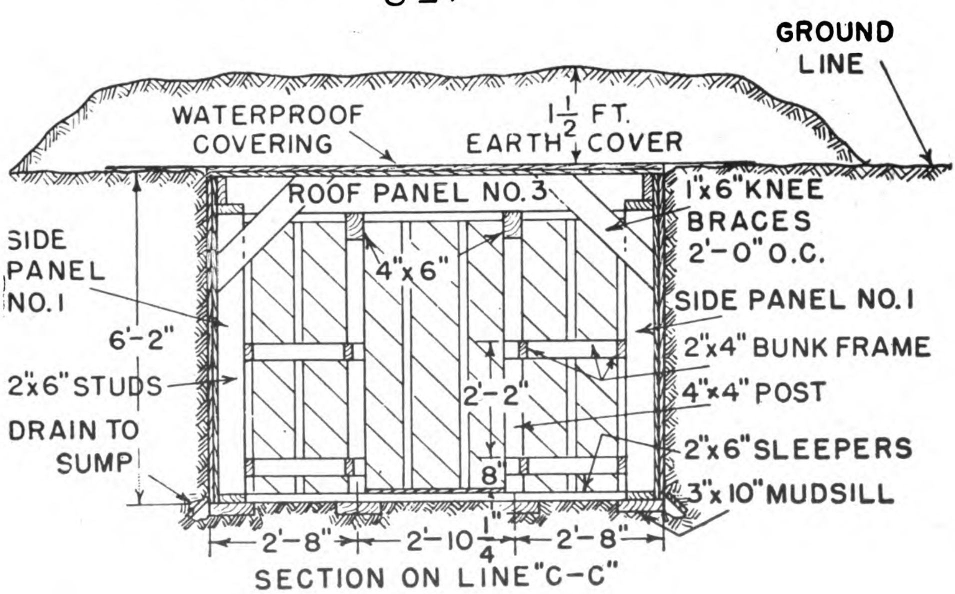


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Figure 179. Continued.

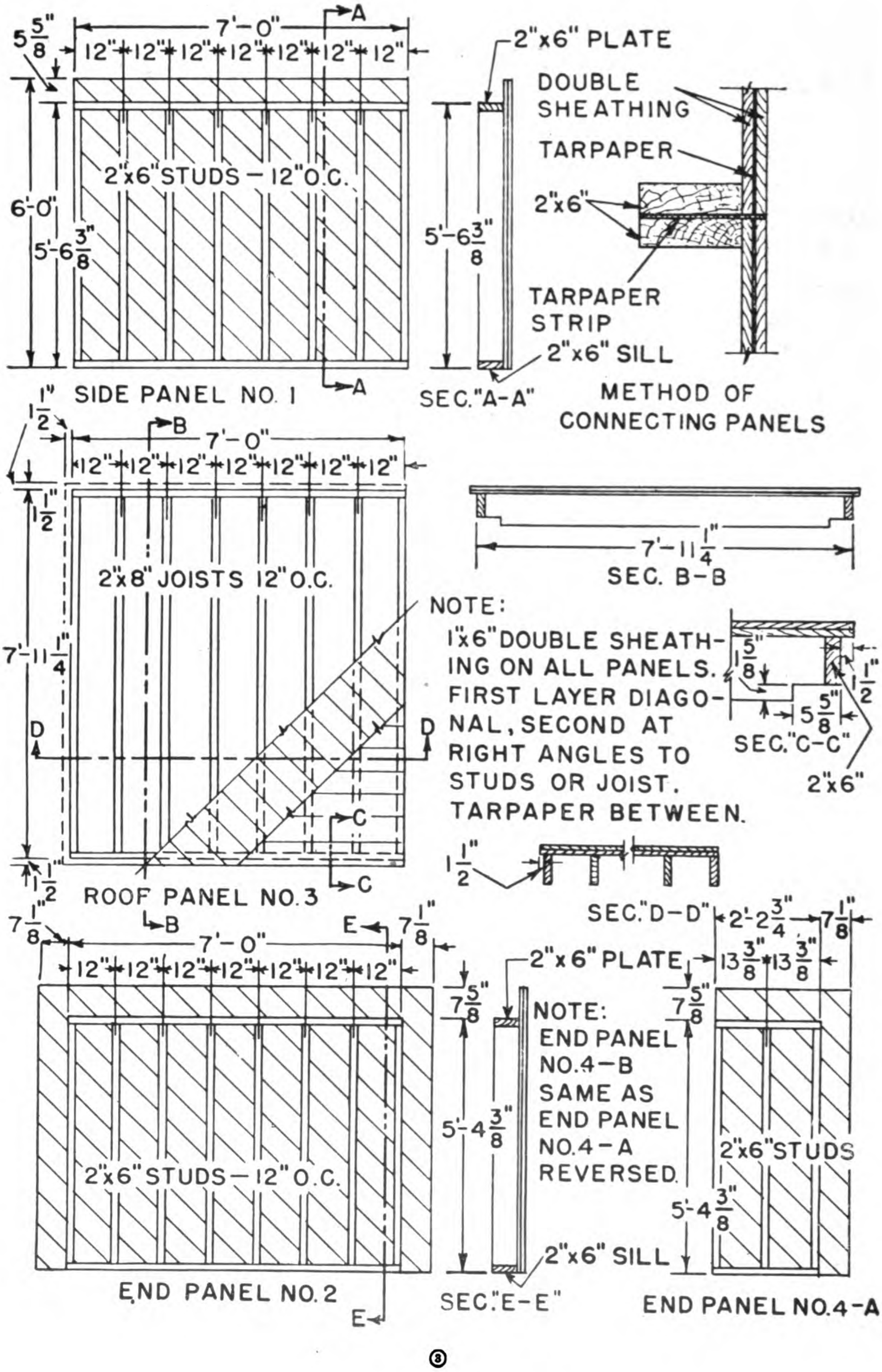

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Figure 179. Continued.

d. Types. (1) Surface shelters usually are built of local materials, dimension lumber, or corrugated metal (figs. 176 and 177). They are an expedient used when the construction of more protective types is restricted by unfavorable conditions of time, soil, or drainage.
(2) Cut-and-cover shelters are of the same general design as surface shelters (figs. 178 and 179). They are buried to give increased protection.
(3) Cave shelters at sites subject to heavy bombing are dug underground or in the side of a hill. Cave shelters are constructed by mining methods, using timber framework to prevent cave-ins (fig. 180). Drainage and ventilation are major problems which must be provided for.

e. Reference. For detailed information on shelters see FM 5–15.

192. GASPROOFING. The following information concerning gasproofing is taken from TM 5–310. For additional information see TM 5–310 and FM 21–40.

a. General. (1) Structural protection against gas—which may be gas, liquids, or finely divided solid matter—must be separated into protection of structural materials and protection of personnel.
(2) The protection of roads and buildings from the effects of chemical agents, excluding incendiary agents, requires a knowledge of gas action on various construction materials. Porous substances, such as brick or concrete, absorb liquid mustard gas fairly readily, chlorine and phosgene in particular attack metals, and some gases are solvents of certain bituminous materials especially those where gas-works products were incorporated in the process of manufacture. Decontamination of roads, walls, floors, and roofs of buildings is facilitated by use of gas-resistant bituminous materials, rustproof sheet metals, and glazed-tile facings.
(3) Protection to personnel further may be classified as individual, tactical, and collective. Individual protection is given by gas masks and special clothing. Tactical protection is gained by the movement of troops to uncontaminated areas. Collective protection is obtained by preventing the entry of gases into structures occupied by personnel who cannot perform their duties efficiently while wearing gas masks, and by providing facilities for the antigas treatment of casualties. This protection must be provided for vital installations at airdromes.
(4) A satisfactory method of collective protection must keep gas out of the structure for definite periods and also must provide sufficient fresh air for the occupants. These requirements may be satisfied by the construction of air locks (fig. 181) at all entrances into the protected space, by making the structure reasonably airtight, and by installing the electrically operated M1 collective protector, a standard piece of equipment issued by the Chemical Warfare Service. These collective protectors, which for safety should be provided with alternative sources of power and spare filters, have a capacity of 12,000 cubic feet of air per hour, sufficient under most conditions for 20 men working in

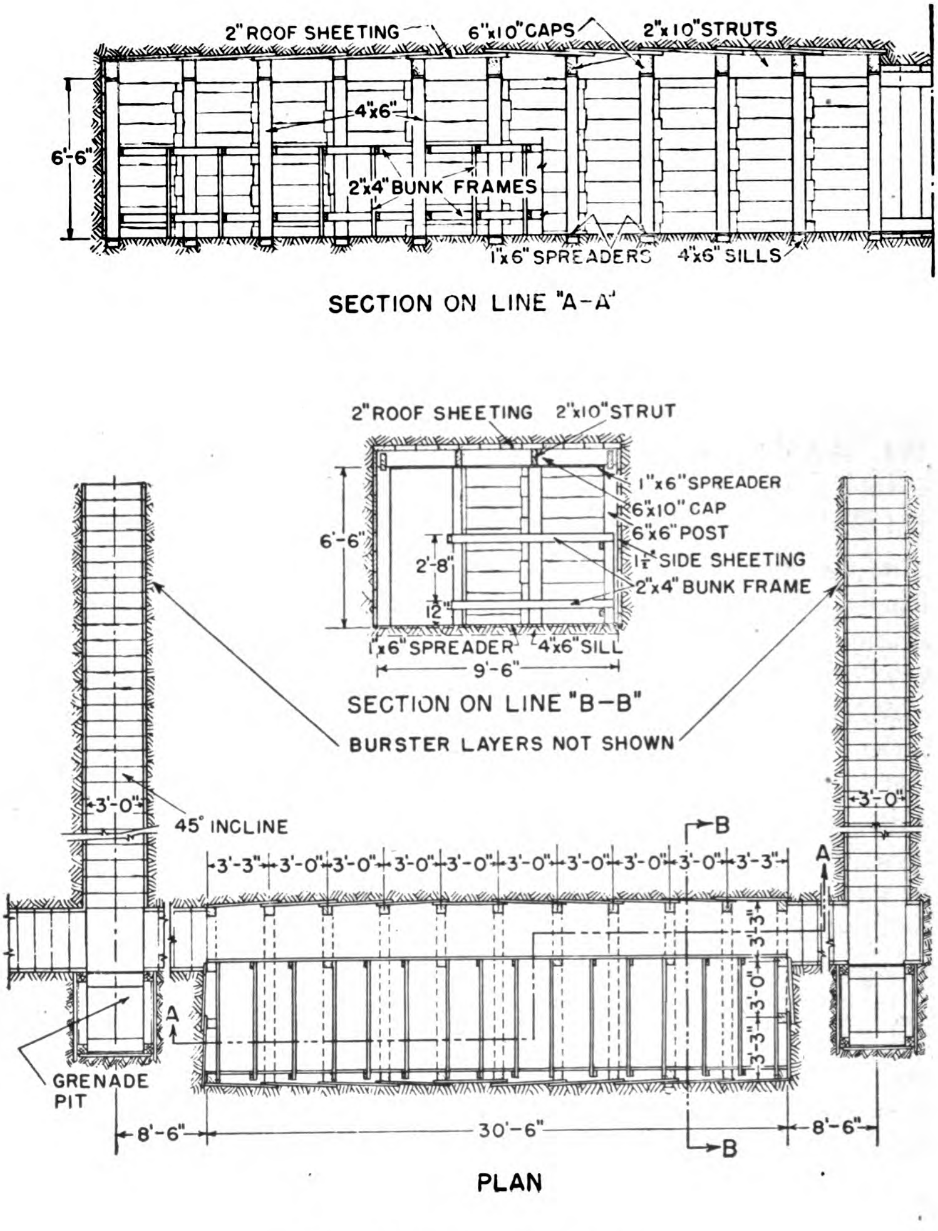


Figure 180. Recess cave shelter.

an operations room. In hot weather the incoming air should be dehumidified by mechanical or chemical means. Positive pressure in the protected space lets purified air leak out and prevents contaminated air leaking in. Collective protectors are supplied for a specific purpose, are expensive, and to produce satisfactory results with proper regard to their capabilities and limitations must be kept in good working order along with their auxiliary equipment.

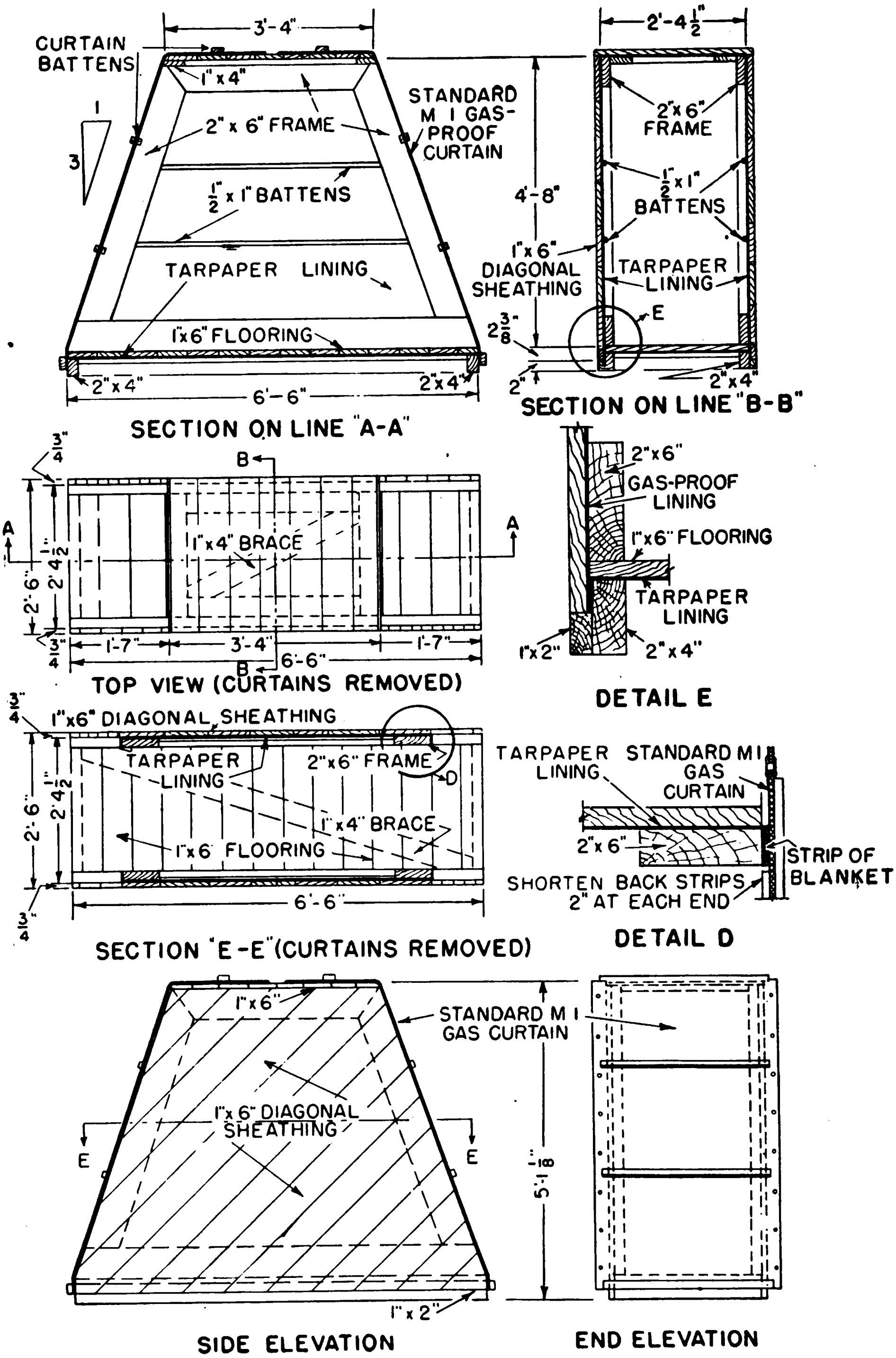


Figure 181. Standard air lock for shelters.

(5) The gasproofing of existing buildings necessarily is of a makeshift nature. In new construction the most effective details can be incorporated at the start, thus obtaining a much more efficient structure for protection against gas attack. A floor raised off the ground must have a double thickness of flooring with bituminous-saturated paper between to make it gasproof.

b. Locations. (1) The gasproofed space, if placed in existing buildings, should be located as far as possible away from light or air shafts where heavy concentrations of gas could remain.
(2) The collective protector is placed in or adjacent to the air locks and separated from the protected space by a wall. The air outlet should be placed so the positive pressure tends to make the air blow through the decontamination areas and air locks into the open air. One-way valves set to the positive pressure attained are placed in the gasproof doors to permit this. The air intake is placed at least 20 feet above the surface of the ground.

c. Open entrenchments. Open entrenchments, if used, are located on the highest terrain available to prevent gas clouds settling in the dugouts and low places.

d. Pipes entering structures. All water and gas pipes and electrical conduits entering the shelters are valved or arranged to prevent combat gases entering if the pipes are shattered outside the structure.

e. Doors. (1) Doors are designed for a horizontal pressure of 100 pounds per square foot when properly screened from blast.
(2) If no screen walls are used, the gasproof door should be staggered in respect to the blastproof and splinterproof door so splinters passing through the latter will not strike it.

193. PROTECTION AGAINST INCENDIARY BOMBS.

In nondispersed areas, subject to constant aerial attack, incendiary bombs cause more damage to buildings than all other types of bombs.

a. Construction materials. Various fireproof materials have been developed and should be used where available. The materials listed in table XXXI are effective provided they are kept in place. If they are loose and exposed to the elements, they may wash or blow away.

Table XXXI. Materials giving protection against burning by the 2.2-pound magnesium incendiary bomb.

Material	Minimum layer (inches)	Weight per square foot (pounds)
Concrete (including cinder concrete)	1	12 or less
Dry earth (sifted)	1¼	6.0
Brick dust	1½	9.5
Dry sand	1¾	13.5

b. Storage of inflammables. All spaces vulnerable to incendiary attack are cleared of wooden goods, waste paper, and oil waste. In warehouses, inflammable materials are stored in small stacks with wide aisles left to permit passage of fire-fighting equipment and to confine fire to small areas.

194. FIRE PROTECTION. The engineer aviation fire-fighting unit is equipped and trained to provide protection from fire. In addition to the special work of this unit, general fire protection is provided by training all troops in fire-prevention and fire-fighting methods; by periodical inspection of storage, housing, and operational areas; by placing and maintaining fire extinguishers, sand piles, water pails, fire axes, and material for combatting incendiary blazes; by organizing and training fire-fighting squads to operate in conjunction with the fire-fighting platoon; and by an effective observation and alarm system. (For methods of fire fighting see TM 5–315.)

195. PROTECTIVE PENS FOR AIRCRAFT. a. Concealment and dispersion are the first steps in protecting airplanes on the ground. Protective pens, sometimes called revetments, also are used. They may be formed by excavating into hills or by constructing an earth traverse around the hard standings (fig. 182). However, the value of such protection must be carefully weighed against the work required to build it. For example, to enclose a hard standing for a B–17 bomber, about 5,000 cubic yards of earth are required for a traverse 14 feet high, trapezoidal in cross section, semicircular in plan, and of sufficient inside diameter to provide wing-tip clearance for the plane to taxi in and turn on the hard standing. Such pens afford protection against bomb fragments from high-altitude bombing but do not prevent effective ground strafing; in fact, they may draw fire if not well concealed. The air force commander determines whether or not pens will be constructed.

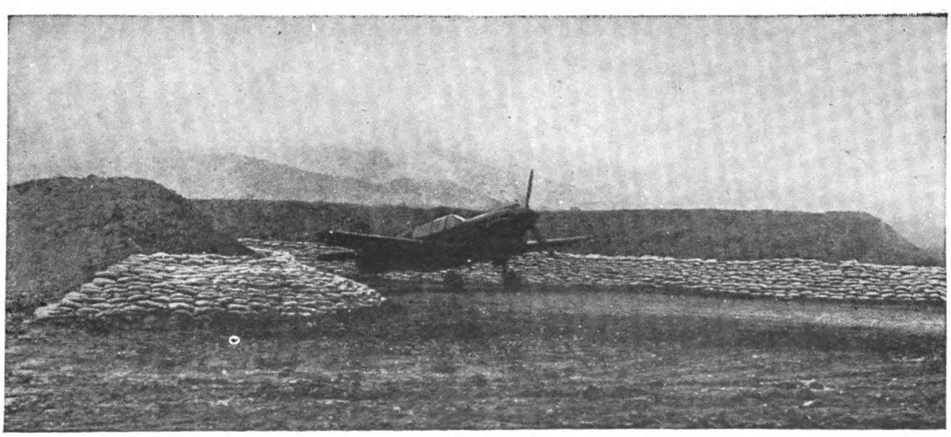


Figure 182. Protective pen for aircraft.

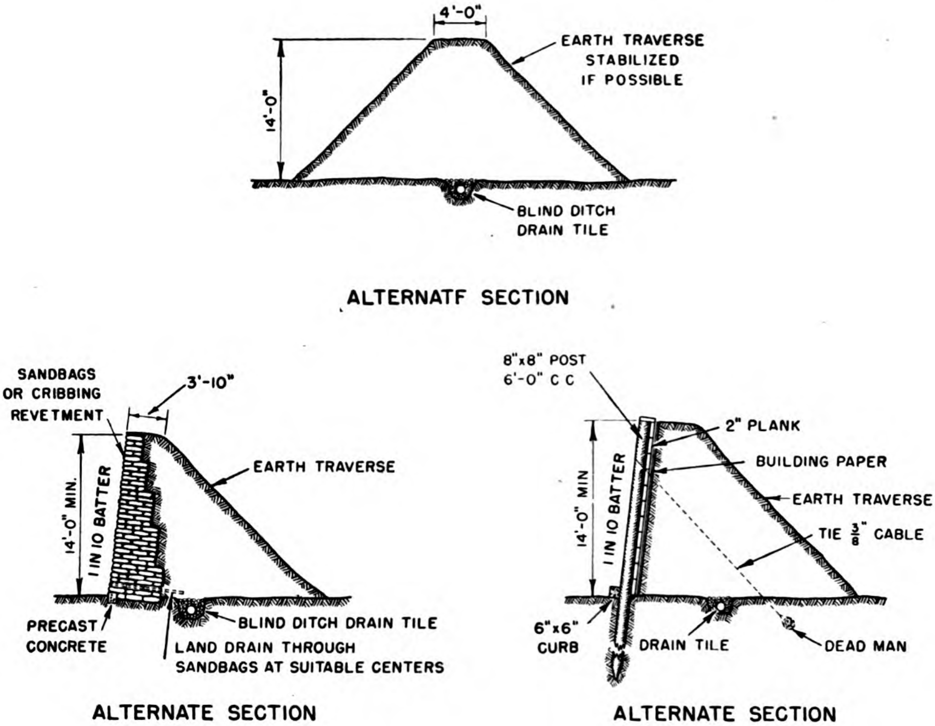


Figure 183. Typical cross sections for protective pens.

b. Where pens are constructed any of the cross sections shown in figure 183 may be used for the traverse. Drainage must be provided. Internal diameter of the pen formed by the traverse depends upon the type and turning characteristics of the plane assigned to the hard standing. (See table XL, app. II.)

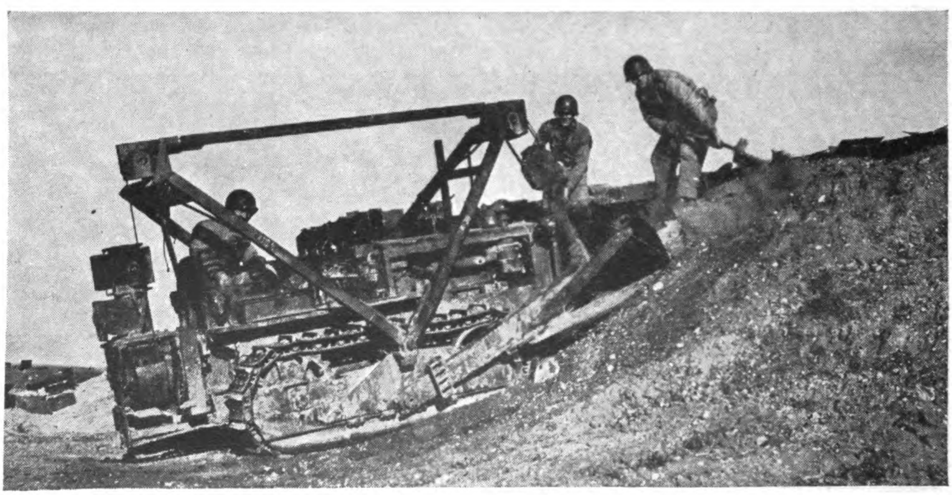


Figure 184. Constructing protective pen with bulldozer.

c. Earth traverses for protecting airplanes may be constructed in several ways. A dragline is effective if fill material is borrowed adjacent to the site. Where fill is hauled in, scrapers supplemented by dozers are used. Small earth traverses are built by dozers alone (fig. 184). Earth traverses are stronger and more resistant to erosion if they are compacted during construction. Growth of vegetation should be encouraged to tone down the surface and to resist erosion.

196. SANDBAG REVETMENTS. **a.** In revetting with sandbags it is important to place the bags correctly or the revetment will not hold together. Correct methods of placing sandbags are shown in figure 185. (For additional information on revetting methods and materials see FM 5–15.)

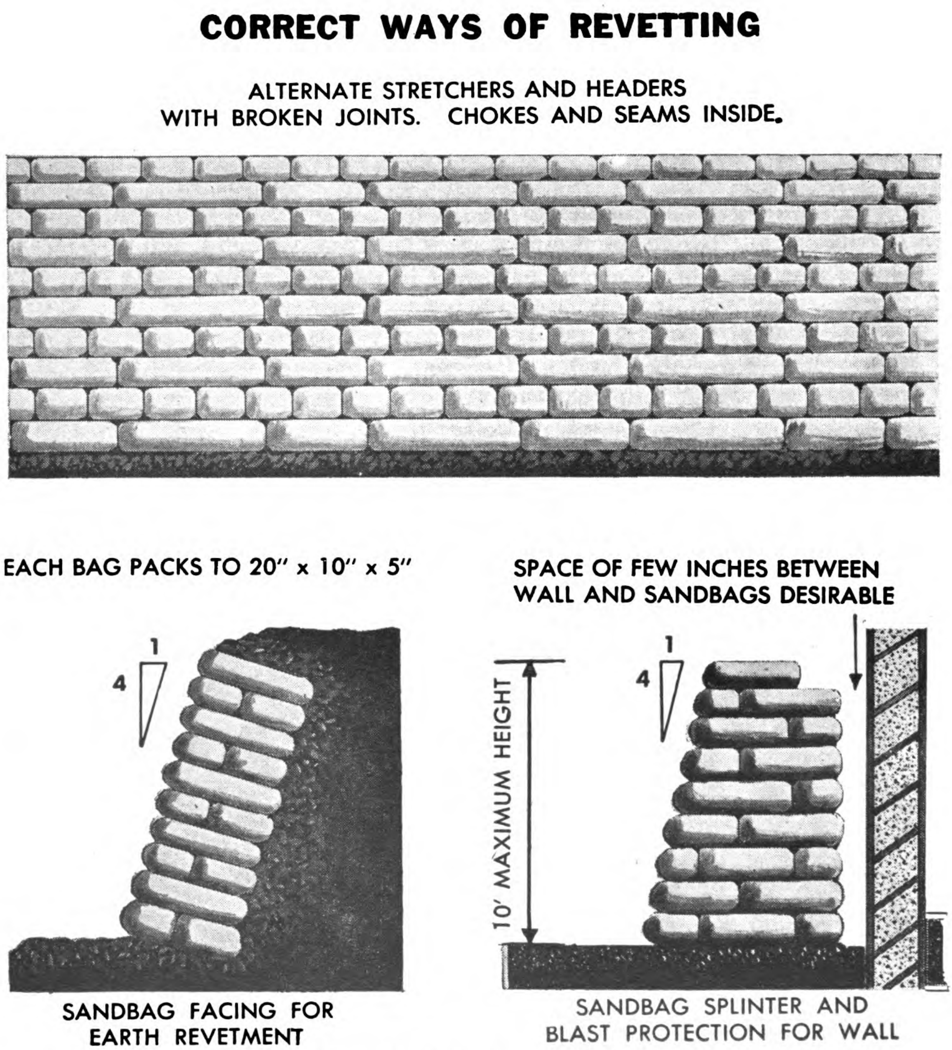


Figure 185. Methods of sandbag revetting.

b. Ordinary sandbags should be used only for temporary revetting. Where bags are to be in place for a month or longer under average rainfall conditions they must be rotproofed or filled with soil stabilized with cement. The latter method usually is easier in the field. The following methods of mildew-proofing and rotproofing sandbags in the field are listed in the order of their effectiveness:

(1) Ten percent of copper naphthenate by weight is dissolved in mineral spirits. Bags are soaked in resulting solution until a test shows an increase in weight of approximately 25 percent, then allowed to dry.

(2) Twenty pounds of copper sulphate is dissolved in 10 gallons of water and 2⅛ gallons of 28-percent ammonium hydroxide added. The bags are dipped in this solution until their weight is increased approximately 40 percent, then allowed to dry.

(3) Bags may be dipped in fluid bituminous materials. These materials are cutback asphalt or cutback tar diluted as needed, or a solution of 20 to 25 percent by weight of asphalt or tar in either gasoline or benzene. The exact amount and type of asphalt or tar must be determined by trial. The bag is soaked in the solution to increase weight not to exceed 100 percent. A satisfactory result is obtained when the dried bag shows no stickiness.

(4) Dissolve 4½ pounds of soda ash or 11½ pounds of soda crystal (sodium carbonate) in 5 gallons of water. Dissolve 10 pounds of copper sulphate in 30 gallons of water in a separate vessel and add 2 ounces of sulphonated pine oil. Dip the bags first in the soda solution and then in the copper sulphate solution, then allow them to dry.

(5) Dilute asphalt emulsion with water so bags dipped in the solution will dry to handle in 3 to 6 hours. This must be determined by trial.

CHAPTER 24

MAINTENANCE, REPAIR, AND REHABILITATION OF AIRDROMES

197. MISSION. The maintenance mission of aviation engineers is to keep the airdromes constantly in condition to serve the aircraft using them. This includes—

a. Routine maintenance.

b. Repair of damage inflicted by the enemy.

c. Stage construction to improve the airdrome.

198. ASSIGNMENT OF PERSONNEL AND EQUIPMENT. The task of maintaining and repairing airdromes is primarily the mission of utilities detachments. Their organic equipment is designed especially for such work. If utilities detachments are not available for maintenance tasks, personnel and equipment must be provided by other aviation engineer units.

199. PLANS. A flexible allotment of personnel and equipment with a reserve for special assignment is necessary for maintenance. For example, a detachment assigned to the maintenance of three airdromes should not be expected to place a third of its personnel and equipment at each airdrome. Instead, depending on local conditions, the detachment commander should place a minimum engineer section with equipment at each airdrome and hold the bulk of his personnel and equipment in a central location prepared to give maximum aid, perhaps after bombardment, where most needed. This central location most likely would be one of the fields where conditions warrant the presence of a larger group.

200. ROUTINE MAINTENANCE AND REPAIRS. a. Scope. Routine maintenance includes inspection and supervision; drainage; repairs to landing strips, taxiways, hard standings, and roads; stock-piling materials for special and emergency repairs; and snow and ice removal.

b. Inspection and supervision. (1) Frequent and careful inspection of an airdrome and continuous supervision of repair work are vital requirements in routine maintenance. An engineer officer should carefully inspect all facilities periodically to detect early evidence of weakness before actual failure occurs. These inspections must be especially vigilant during rainy seasons and spring thaws. Dangerous areas must be marked.

(2) Every defect discovered during inspections must be studied to determine its cause. Surface defects may result from imperfections in base construction, concentrated use (as in turn-around areas), or inadequate drainage. Simple rules for classifying defects cannot be given. Each must be studied as an individual problem to determine the appropriate remedy. It is especially important properly to interpret first evidences of major defects. Surface patching will not correct a subgrade or base-course deficiency.
(3) The drainage system at a new airdrome is carefully observed for hydraulic deficiencies during first storms and the spring run-off. The system also is inspected for erosion damage and clogged drains after storms.

c. Drainage. Drainage ditches must be kept clear of weeds, brush, silt, and other accumulations of debris that obstruct the flow of water. Erosion damage to ditches often is corrected after a storm by backfilling and placing riprap, or by lining with compacted bituminous premix. Clogged drain and culvert pipe must be opened by cleaning. Any deficiencies in the original drainage system lay-out must be corrected as they are discovered. Special attention must be given to drainage maintenance during periods of thaw especially when there are accumulations of snow. Open side ditches are cleared of snow and channels are opened through snow accumulations on the shoulders whenever needed to permit water to escape. Every precaution must be taken to prevent ponding of snow-melt water on the runway, on the shoulders, or in the side channels.

d. Repairs to runways, taxiways, hard standings, and roads.
(1) BASE (*a*) All soft and yielding spots or areas that develop in runways must be corrected. Early surface indications of soft spots in the base or subgrade under flexible pavements often are similar to first evidence of defects in the pavement itself, and it is important to differentiate the two. Soft spots may develop slowly at first, but they progress rapidly to failure with the possibility of serious consequences if not repaired. For example, an area of bituminous pavement that is too rich in bitumen will be displaced in much the same manner as the beginning surface displacement resulting from soft subgrade or a frost boil. The remedy for a poor subgrade or base may involve considerable work. Exploratory excavation may be required to determine the nature of the trouble and the extent of repair required.

(*b*) If the weakness is in the subgrade, it is uncovered and the unsatisfactory soil removed and replaced with well-graded granular material, thoroughly consolidated. If the weakness results from seepage it is necessary to install a drain. If the difficulty results from frost action in the form of frost boils, frequently it is necessary both to replace the frost-action subgrade soil with granular material and to install special drains.

(*c*) Sometimes drainage measures alone will correct frost difficulties because heaving cannot occur unless there is a water supply to freeze and build up subsurface ice layers or lenses. A critical time for weakness resulting from frost action is in the spring when the ice in the base and subgrade melts and saturates the foundation.

Figure 186. Failure of natural surface. Plane has bogged down where it left surface runway.

(2) SURFACE. (*a*) *Earth landing strips* having no surface treatment other than compaction are kept in condition for dry-weather operation by sprinkling, blading, and rolling. Dust palliatives may be used to advantage. (See ch. 17.) Rain water is removed quickly by maintaining transverse slope and providing adequate discharge of collected water into natural drainage channels away from the field. This permits the surface to dry in a short time, resulting in a minimum of time lost to aircraft using the field (fig. 186).

(*b*) *Untreated base courses* on runways and taxiways require continuous maintenance. This consists of light scarifying or blading with a grader followed by sprinkling and rolling. If small areas start to ravel or to develop ruts or chuck holes, these are patched with a stabilized-soil mixture, following the procedure described in (*c*) below for patching bituminous pavements. Dust palliatives may be applied as part of the maintenance program (ch. 17).

(*c*) *Bituminous surface treatments and pavements* usually require some maintenance, especially near the ends of runways and on taxiways and hard standings where aircraft do considerable turning. Surface abrasions and wear may be corrected by a bituminous surface treatment using the asphalt-kettle hand spray (fig. 211). This involves sweeping the worn area, spraying with cutback or emulsified asphalt or with tar, covering with clean mineral aggregate, and compacting. Deeper wear, as in mixed-in-place bituminous pave-

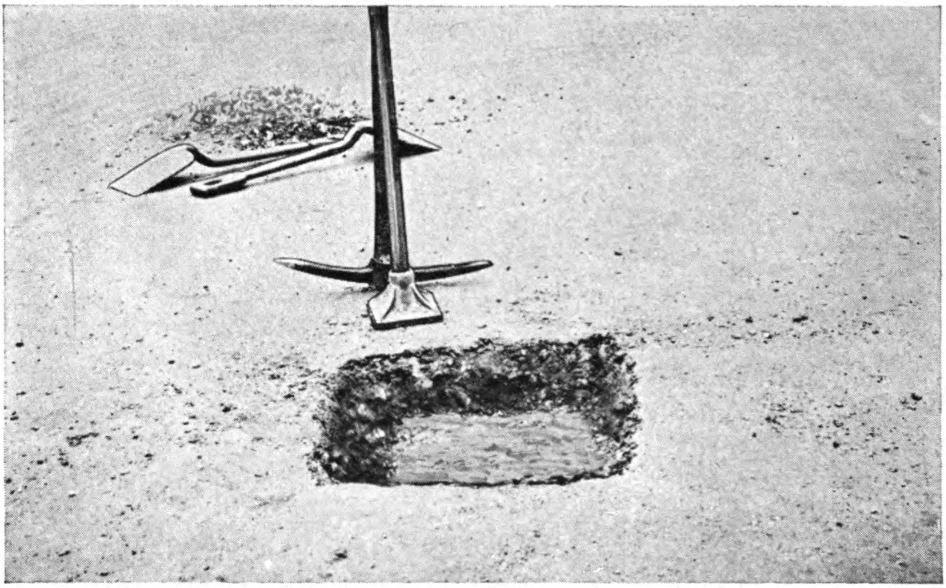


Figure 187. Hole in damaged pavement trimmed for patching.

ments, may require removal of the damaged pavement and replacement with bituminous premix patching material. In this type of patching edges of the surface are trimmed vertically after the defective area is removed. The outline of the area to be patched is cut in straight lines parallel and perpendicular to the runway center line. The bottom is cleaned out and compacted (fig. 187). Before placing the patching material the vertical edges of the cut-out pavement are painted with cutback or emulsified asphalt to promote bond between old and new materials. The patching material is evenly spread, then compacted to grade by rolling. Waves (wrinkles or shoves) that sometimes develop in mixed-in-place or cold-laid bituminous pavements may result from insufficient stability in the pavement itself or from slippage of the pavement on the base course.

Instability in the pavement may be caused by poor aggregate grading, too much bitumen in the mixture, or insufficient curing and compaction. So long as the displacement is confined to movement in the pavement and does not result from a yielding foundation, the remedy is simple. The defective area may be scarified, reworked, and relaid; or, it may be scarified, removed, and replaced with premix patching material. Scarifying should not be deep enough to disturb the base. Waves caused by slipping on the base require removal of the pavement and elimination of the slip plane. A frequent cause of this trouble is an accumulation of soil binder on top of a base not properly mixed during original construction. This accumulation must be removed, replaced with granular material, compacted, and primed before replacing the pavement.

(*d*) *Concrete* slab maintenance is done during favorable dry weather, if possible. Joints and cracks in slabs are sealed with hot asphalt or tar. Depressed and broken slabs are resurfaced with bituminous premix to bring runway surfaces up to grade. The area to be resurfaced is cleaned, then a light tack coat of RC–3 cutback asphalt or RS–1 emulsified asphalt is applied at about 0.1 gallon per square yard. The premix then is spread to required thickness by hand raking. The edges of the patch are "feathered" by raking, and the whole patch compacted by rolling. Broken slabs resulting from major foundation defects or bombing are replaced with concrete or bituminous mixture after the foundation is repaired.

(*e*) *Steel landing mats* are repaired as described in paragraph 140.

e. Stock piles. Pits must be opened and stock piles of sand and gravel, base material, and premix patching material must be prepared at convenient places and in ample quantities ready for emergency maintenance. These stock piles must be arranged for quick loading and transportation to the runways. For base materials, loading traps or other improvised arrangements are prepared in advance (figs. 188, 189, and 190). Premix patching material may be prepared by mixed-in-place methods, using a motor grader. (See par. 156 for description of mixing, and table VIII for materials.) The mixed material is left in windrows for later use.

f. Snow. (1) GENERAL. Standing orders should cover responsibilities, priorities, safety precautions, and operational requirements with respect to snow and ice. Factors to be considered in planning the snow-handling program are climatic conditions, aircraft to be accommodated, equipment available for handling snow, and camouflage requirements. Airplanes may be equipped

Figure 188. Trap for loading trucks.

Figure 189. Chute for loading trucks.

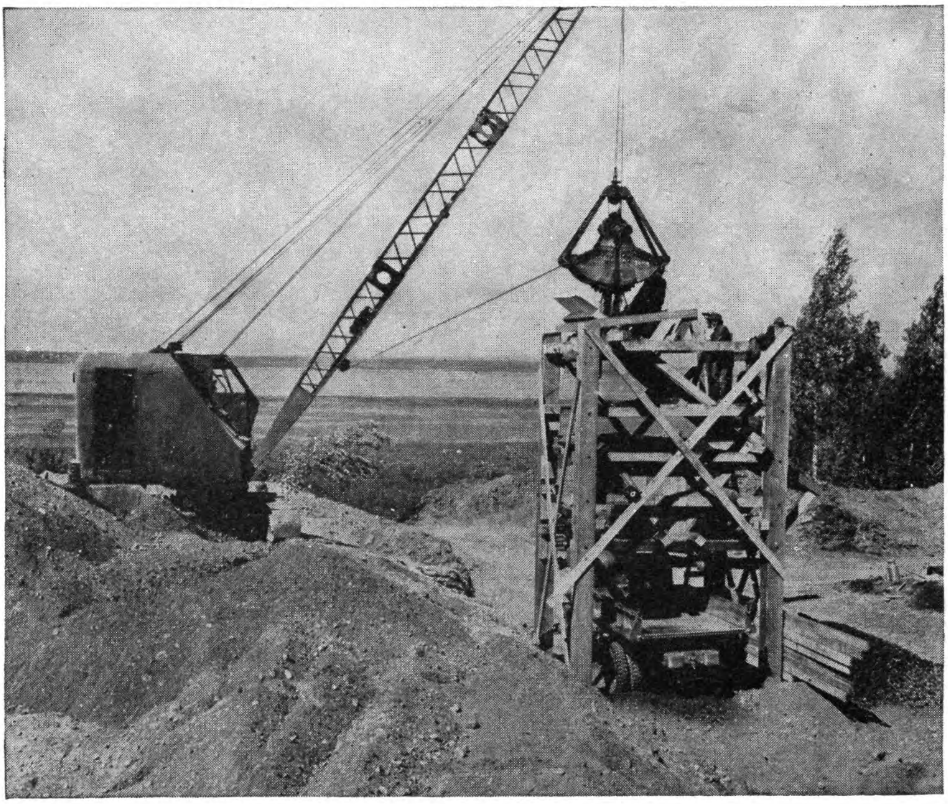


Figure 190. Sand sifter. By removing screens it may be used for loading bank-run gravel.

with landing skis or wheels. Ski-equipped airplanes operate successfully on packed snow while airplanes with landing wheels can operate in not more than 3 inches of loose snow. This may be fresh snow on a cleared runway, fresh snow on previously packed snow, or melting snow previously packed on a runway. Maintenance operations continually must reduce the thickness of packed snow so there will be no more than 3 inches on the runway when a thaw comes. From the standpoint of camouflage it is undesirable to remove all snow from a runway when the surrounding terrain is blanketed with snow.

(2) EQUIPMENT. Equipment for handling snow consists of equipment organic with aviation engineers, supplemented by other equipment issued from depots to fill particular needs. Equipment from depots includes such pieces as **V**- and one-way push plows, rotary plows, rollers, and others specially developed for unusual snow conditions (figs. 191 and 192). Many expedients are workable in field operations.

(3) METHODS. (*a*) In regions of heavy snowfall, with prolonged cold weather relatively free from sudden thaws, snow may be handled by packing. Rolling begins as soon as 3 inches of fresh snow have fallen, and continues during the snowfall. During rolling the snow is dragged or scraped to give

Figure 191. One-way-push snow plow.

Figure 192. Rotary snow plow.

a smooth surface. The runway, shoulders, and as much adjacent area as practicable are packed. Accumulated packed snow on runway and shoulders is removed as the season progresses, so a sudden thaw will not leave a blanket of soft snow too thick for airplane operation.

(*b*) Snow is packed by a set of three rollers (fig. 193) drawn by a tractor with snow treads. Each roller is 4 feet 8½ inches outside diameter and 10 feet 3½ inches long, with a shell of 10-gauge corrugated metal. Over-all axle length of each roller is 11 feet 9 inches. The corrugated metal shell is supported on the axle by two structural frames, or spiders, at the third points and two steel-plate bulkheads at each end. One of the plates has a manhole. The three rollers are arranged one in front and two in line immediately behind the first. **A**-frames attach each rear roller to one end of the axle of the front roller and the front roller to the tractor. Dragging for smoothing is done with a drag equipped with metal cutting edges front and rear (fig. 193), or with a grader.

(*c*) Another type of roller that has been used successfully to pack snow for light airplanes is constructed mainly of wood, is 8 feet in diameter, 10 feet long, and weighs about 1,000 pounds. Two-inch pipe is used for the axle. Five circular ribs, built of lumber 2 inches thick, are mounted on the axle at 2½-foot intervals. These ribs are covered with 1- by 4-inch boards placed longitudinally to form the surface of the roller.

(4) METHODS OF CLEARING AND REMOVING. Clearing and removal of snow is required in regions where climatic conditions will not permit snow-packing. Snow-clearing may be accomplished with a ballasted truck with a snow plow on the front which has a rolling caster at each end to keep it about ½ inch above the runway surface; grader; angledozer; tractor with one-way or **V**-type blade; and rotary snow plow. The truck and grader may be used for light snowfalls. They start at the center of the runway and move the snow to the sides progressively with each lengthwise trip. The angledozer, or a tractor with one-way snow blade, is used to clear heavy snowfalls and to move windrows accumulated by the truck and grader. Drifts may be opened by a tractor with **V**-type blade or by the rotary snow plow. Rapid removal of heavy snow requires a rotary plow or other special equipment. As an expedient in the absence of this equipment snow may be loaded on tractor-drawn sleighs built of lumber. Even if rotary plows are available sleighs may be used to remove snow from necessary work areas around buildings.

g. Ice. Ice coatings on runways, taxiways, and hard standings are sprinkled with sand spread by hand, or by mechanical spreaders issued from depot stock (fig. 194). If practicable, sand should be heated before spreading. Salt (sodium chloride and calcium chloride) is not used for ice control on airdromes without specific air force approval because it promotes corrosion of metal aircraft parts. Accumulated sand on runways and taxiways is removed in the spring by power brooming.

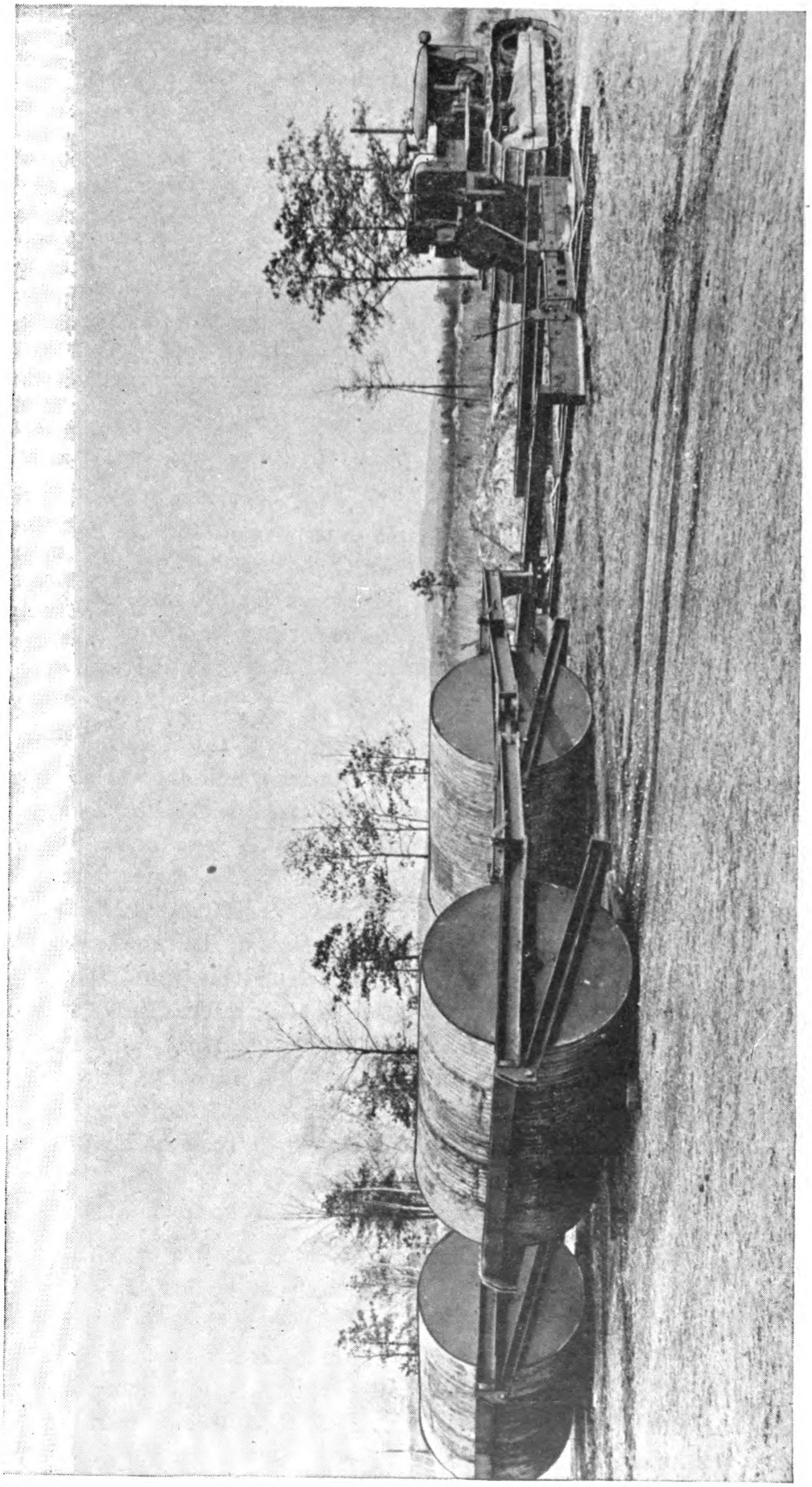


Figure 193. Rollers for packing snow, and drag with metal-cutting edges.

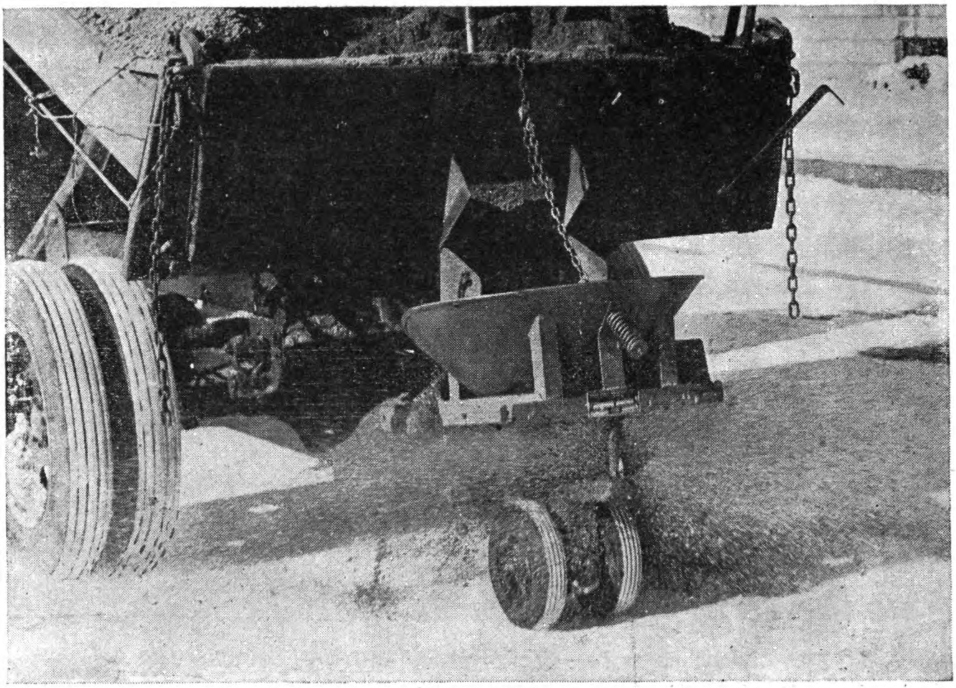


Figure 194. Mechanical sander.

201. REPAIR OF DAMAGE BY ENEMY. a. Scope. Emergency maintenance after bombing is concerned primarily with quick repair and clearing of the runway and necessary taxiways, followed by other repairs as needed.

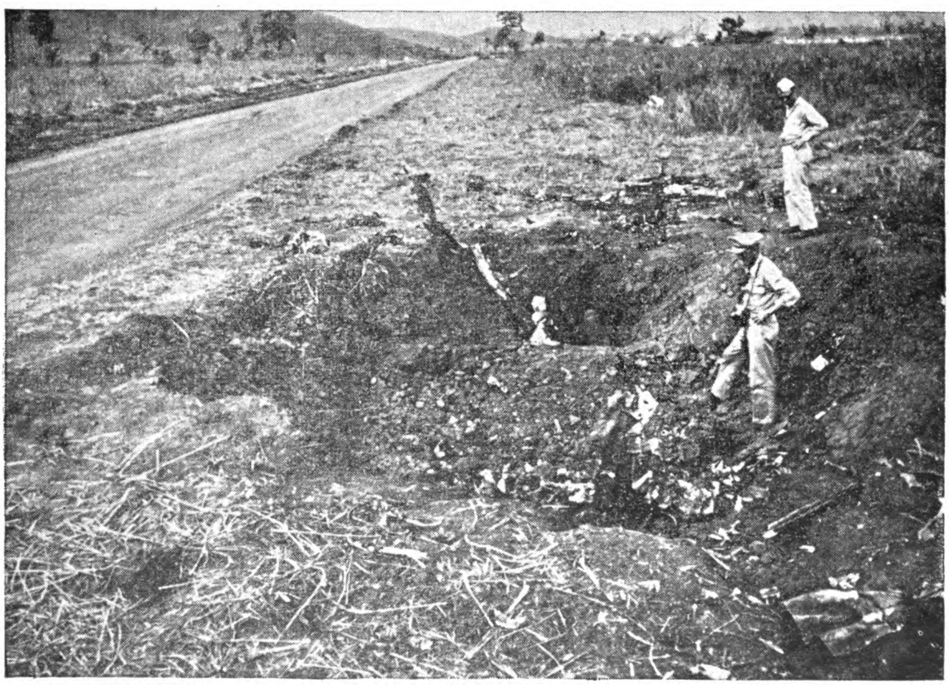


Figure 195. Crater caused by enemy bomber crashing with bomb load.

Speedy repairs depend largely upon advance preparation, training, and use of equipment rather than hand labor.

b. Reconnaissance. Hasty reconnaissance is made as soon as possible; meanwhile work is started on obviously needed repairs. Reconnaissance should be alert for subterranean craters formed by bombs exploding at considerable depth, and for delayed-action bombs.

c. Craters. (1) The size of bomb craters depends upon the size and type of bomb (fig. 195). Table XXXII gives the characteristics of craters caused by various-size, general-purpose bombs. Material from opened pits or stock piles is used for fill. In an emergency fill material may be borrowed from the shoulders of the runway and replaced at a later date. Compacting during filling is important. Repaired craters must be inspected periodically for softening and settlement, especially after the first rain.

Table XXXII. Characteristics of craters caused by various-size general-purpose bombs in sandy soil.

Weight of bomb (pounds)	With instantaneous fuze			With delay fuze		
	Depth of crater (feet)	Diameter at surface (feet)	Material displaced (cubic yards)	Depth of crater (feet)	Diameter of surface (feet)	Material displaced (cubic yards)
100	2	9	4	5	20	30
300	3	13	10	7	27	70
600	5	17	17	10	37	170
1,100	6	20	28	13	45	320
2,000	7	22	47	17	50	600

(2) The procedure for repairing craters is—

(*a*) Remove damaged surface. Trim sides of crater, placing loose earth in bottom.

(*b*) Compact loose earth in bottom with compressor attachments, or by hand methods if equipment is not available (fig. 196).

(*c*) Fill crater to level of subgrade, compacting in layers by power or hand methods. The dozer gives good compaction after crater is filled enough so it can operate in the hole (fig. 197).

(*d*) Trim sides of pavement and base course to vertical edges.

(*e*) Repair surface as described in paragraph 200**d**.

d. Removing debris. Damaged planes, equipment, landing mats, and other objects are pulled from the runway to the shoulder and removed later (fig. 198). Metal objects and fragments from shells and bombs are a serious menace to tires and must be removed before airplanes operate. Removal may be effected by work parties in line across the runways and taxiways, working from end to end. If available, truck-mounted magnetic removers will speed the work.

Figure 196. Pneumatic tamper compacting loose earth in bottom of bomb crater.

202. REHABILITATION OF CAPTURED AIRDROMES. a. Scope. This involves essentially the same work and procedure as repair of damage discussed in paragraph 201, but advance planning is more difficult and every effort should be made to study the latest aerial photographs before moving to the site. Air reconnaissance by engineer personnel is made when possible.

Figure 197. Bomb crater being filled and compacted with dozer.

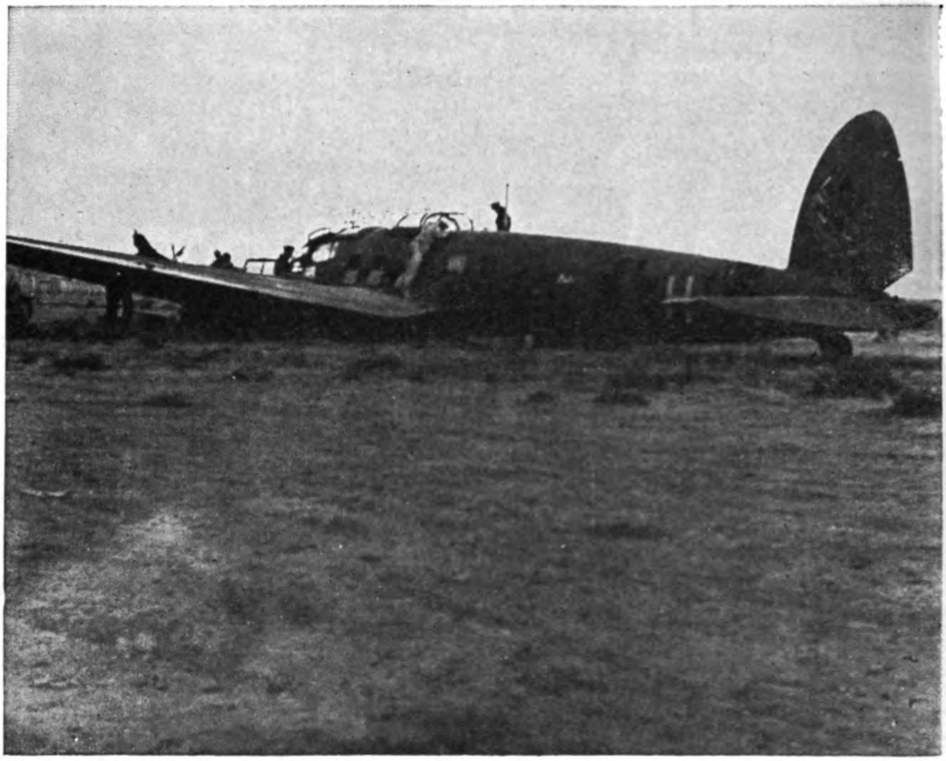


Figure 198. Damaged plane pulled to shoulder awaiting removal.

b. Enemy action. The enemy may be expected to do his utmost to prevent or delay our use of evacuated airdromes. *If he has time he will place delayed-action bombs, mines, and booby traps throughout the area.*

c. Necessary work. The first objective of troops restoring the airdrome will be to provide first-stage requirements for immediate operation by friendly aircraft. To do this they must—

(1) Remove delayed-action bombs (fig. 199), mines, and booby traps. Electric mine detectors may be ineffective because of the large amount of metal from wreckage, fragments, and shell cases which are strewn over an area after an engagement. If this is the case hand probing methods must be used. Culverts and other covered drains are likely places for delayed-action bombs.

(2) Fill craters and repair surfacing on runways and taxiways. (See pars. 200 and 201.)

(3) Restore drainage system or provide a new one.

d. Construction units. Initial restoration of the airdrome is accomplished by whatever troops and equipment are immediately available, ranging from infantry troops working with entrenching tools to aviation engineer troops with a full complement of organic equipment.

Figure 199. Removing unexploded bomb.

203. IMPROVEMENTS. Improvements at an airdrome are accomplished by the maintenance troops assigned to it (par. 198) or by local labor supervised by maintenance units. After minimum requirements for air operations have been fulfilled at an advanced landing field, the following improvements may be made as part of the program of stage construction (par. 52):

a. Extend and improve runways, taxiways, hard standings, roads, and drainage. This work must be coordinated with air operations. To extend runways work is started at the end of the existing construction and continued outward.

b. Provide buildings for operations, control tower, crew shelters, communications center, and other technical facilities.

c. Improve camouflage of vital installations by placing flat-tops or drapes over essential objects, and by use of decoys.

d. Improve utilities by adding pumping facilities, pipe lines, and storage tanks.

e. Provide messing, bathing, and recreational facilities for personnel.

f. Plant grass to provide a turf surface on shoulders and graded areas. Table XXXIII gives characteristics of native grasses. Turf aids camouflage and reduces dust and erosion. This treatment is limited to geographical areas with favorable climate.

Table XXXIII. Characteristics of grasses.

Name of grass, grouped by region of suitability	Resistance to traffic wear and mowing	Preferred soil texture [1]	Drought resistance	Acid tolerance	Rate of establishment	Method of establishment	Best season for work	Use in mixture with
TURF GRASSES								
Cool humid region								
1. Kentucky bluegrass (Poa pratensis)	Good	Loam, clayey loam	Good	Fair	Slow	Seed, sod	Fall or spring	2
2. Perennial ryegrass (Lolium perenne)	Excellent	Various	Good	Good	Fast	Seed	Fall, or spring	1
Warm humid region								
3. Bermudagrass (Cynodon dactylon)	Excellent	Sandy to clayey loam	Excellent	....	Fast	Sprigs, sod, seed	Spring or summer	Seed along or with carpet grasses
4. Common carpetgrass (Axonopus affinis)	Good	Moist clays, clayey loam	Fair	....	Medium, Fast	Seed, sod	Spring or summer	Do.
5. St. Augustinegrass (Stenotaphrum secundatum)	Fair	Moist, various	Fair	....	Fast	Sprigs	Spring or summer	....
Dry region								
6. Buffalo grass (Buchloe dactyloides)	Excellent	Clayey loam to loam	Excellent	....	Medium, Fast	Block, sod	Spring	Seed glue grama between buffalo-grass-sod blocks.
7. Smooth brome (Bromus inermis)	Good	Various	Good	....	Medium, Fast	Seed	Spring	Mix with native grass

ROUGH TURF AND BUNCH GRASSES

Cool humid region								
8. Common ryegrass (Lolium multiflorum and L-perenne)	Good	Various	Good	Good	Fast	Seed	Fall or spring	9
9. Orchardgrass (Dactylis glomerata)	Fair	Loam to clay	Good	Excellent	Fast	Seed	Fall or spring	8
Warm humid region								
10. Hairy crabgrass (Digitaria sanguinalis)	Excellent	Loam to clay	Excellent	....	Fast	Hay-seeding	Summer	....
11. Bluestem (broomsedge) (Andropogan) [2]	Fair	Loam to clay	Excellent	Excellent	Medium	Hay-seeding	Fall	....
12. Korean lespedeza (Lespedeza stipulacea)	Excellent	Loam to clay	Excellent	....	Medium	Seed	Spring	....
Dry region								
13. Little bluestem (Andropogon scoporius)	....	Moist, sandy to loamy	....	....	....	Seed, hay-seeding	Spring	Other grasses suited to soil
14. Blue grama (Bouteloug gracilis)	....	Loam to clay	....	....	....	Seed, hay-seeding	Spring	Seed between blocks of Bermuda grass
15. Crested wheatgrass (Agropyron cristatum)	....	Clayey loam to loam	....	....	Slow	Seed	Spring	Other native grasses

[1] For explanation of soil texture terms see table VI.
[2] Species.

CHAPTER 25

EQUIPMENT

204. ORGANIC EQUIPMENT. The equipment issued aviation engineers has been selected for its usefulness in airdrome construction and maintenance. Its proper use is essential to fulfillment of the mission. It consists principally of standard commercial items of heavy earth-moving and compaction machinery, together with other items also issued to general service and combat engineers. See table XXXIV for weapons, table XXXV for organic equipment of engineer aviation battalions, table XXXVI for equipment of the airborne engineer aviation battalion, and table XXXVII for special equipment of the fire fighting unit.

205. CLASS IV HEAVY CONSTRUCTION EQUIPMENT. a. Other equipment not organically issued to aviation engineer troops is obtained from theater of operations depots. This is largely heavy construction equipment for providing various types of pavements for runways. It consists of asphalt, concrete, and aggregate production plants and auxiliary equipment. Available items are shown in the Equipment List, Standard Makes and Models, published by the Engineering Division, Office, Chief of Engineers. For information on some of the main items of class IV equipment see table XXXVIII. Requirements in different theaters of operations vary and depots may not have identical equipment.

b. The asphalt plant, table XXXVIII, is issued in two sizes: a 25 ton per hour plant (fig. 263), and an 80 to 150 ton per-hour plant (fig. 264). The larger plant contains ten units. It can be assembled as a central mixing plant, or the mixer and the crawler-mounted bucket loader can be combined to form a traveling mixer for mixed-in-place construction (fig. 265).

c. Aggregate production plants, table XXXVIII, are issued in four sizes: a 7 cubic yard per hour jaw type rock crusher (fig. 270); a 25 ton per hour crushing and screening plant containing two units (fig. 271); a 100 ton per hour gravel-crushing and screening plant, consisting of five units; and a 150 ton per hour crushing, screening, and washing plant consisting of nine units (fig. 272).

d. For units in the concrete plant see table XXXVIII and figures 266, 267, 268, and 269.

e. The major items of auxiliary equipment are given in table XXXVIII.

Table XXXIV. Weapons, engineer aviation battalion.

Item	Headquarters and headquarters company	Company	Total
Carbine, cal. .30, M1, A2	74	36	182
Gun, machine, cal. .50, M2 (WC), flexible	4	4	16
Gun, machine, cal. .50, M2 (HB), flexible	6	—	6
Gun, submachine, cal. .45, M3	9	8	33
Launcher, rocket, AT, cal. 2.36, M1	8	—	8
Launcher, grenade, M7	10	—	10
Mortar, 60-mm, M2, with mount	2	2	8
Mount, MG, cal. .50, AA, M3	4	4	16
Pistol, automatic, cal. .45	2	—	2
Rifle, US, cal. .30, M1	155	142	581
Carriage, motor, multiple gun, M16	1	1	4

*Table XXXV. Organic equipment, engineer aviation battalion.**

Item	Units available			Hourly fuel consumption (gallons)	Weight loaded (1,000 lb.)	Dimensions			Figure number
	Headquarters and headquarters company	Company	Total			Length	Width	Height	
Engineer issue, nonmotorized									
Blacksmith equipment, set No. 1, engineers	1	1	4						
Binder, load, lever type, heavy-duty	10	6	28		.018	2′0″			
Camouflage equipment, set No. 1, aviation engineers	1		1						
Canvas, worker's equipment, set No. 1	1		1						
Carpenter equipment:									
Set No. 1, engineer squad	3	9	30						
Set No. 3, engineer combat platoon	1	3	10						
Compressor, air, trailer-mounted, steel-wheels, Diesel-engine-driven, 315 cfm.	1		1						203
Crane, tractor-operated, nonrevolving, 40,000-lb. capacity at 10-ft. radius, 20-ft. boom	1		1		7.3	30′5″	9′6″	22′6″	204
Cultivator, chisel-tooth, 12-in. spacing, 8-ft. wide	1		1		2.37	12′3″	8′0″	4′ ½″	205
Demolition equipment:									
Set No. 1, engineer squad	1	9	28						
Set No. 2, engineer platoon	1	3	10						
Distributor, bituminous-materials trailer-mounted, 1,250-gal.	1		1	Gas 1 Diesel 6	20.98	20′4″	7′9″	8′9″	206
Electric lighting equipment set No. 3, 3 kva.		1	3						

Table XXXV. Organic equipment, engineer aviation battalion.—Continued.*

Electric lighting equipment, set No. 4, 5-kw.	1		1						
Floodlight, carbide, portable, 8000 candlepower	10	6	28		.06	10″	10″	3′0″	
Floodlight, electric, 150-w.	20	1	50						
Grader, road, towed-type, leaning wheel, hand-controlled, 12-ft. moldboard	2		2		12.175	31′7½″	12′0″	7′5″	207
Harrow, disk, offset, 24-in. disks	2		2		2.37	15′0″	9′10″	2′0″	208
Harrow, spike-tooth, 4-section	1		1		.54	10′0″	20′0″		209
Heater, asphalt, trailer-mounted, three-car, 42-h.p. boiler	1		1	0.44 (engine) 3.5 (burner)	4.98 empty	13′8″	5′7″	5′8″	210
Kettle, asphalt-repair, trailer-mounted, with motor-driven hand spray, 165-gallon capacity	1	1	4	0.5 (engine) 2.5 (burner)	2.9	10′6″	5′4″	6′0″	211
Laboratory, soil-testing, set No. 1, aviation battalion	1		1						212
Lubricator, trailor-mounted	1	1	4	0.44	4.0	12′1″	5′10″	6′1″	213
Mixer, concrete, gasoline-engine-driven, trailer-mounted, 14-cu. ft.	2		2						214
Mixer, rotary-tiller, soil-stabilization, gasoline-engine-driven, self-powered, trailer-mounted	2		2	5	4.625	16′2″	6′8″	7′8″	215
Mower, tractor-drawn, cutter-bar-type, steel-tired, 7-ft. cutter-bar	1		1		.82	7′1″	11′6″	5′8″	216

Table XXXV. Organic equipment, engineer aviation battalion.—Continued.*

Item	Units available			Hourly fuel consumption (gallons)	Weight loaded (1,000 lb.)	Dimensions			Figure number
	Headquarters and headquarters company	Com-pany	Total			Length	Width	Height	
Pioneer equipment:									
Set No. 1, engineer squad	2	9	29						
Set No. 2, engineer combat platoon	1	3	10						
Pipefitting equipment, set No. 1	1	1	4						
Plates, street, tractor, set No. 1 plow	1		1						
Plow, bottom and disk, towed-type, four 14-inch bottoms	1		1						
Plow, tractor, with standing cutter, and single-plain share		1	3		2.50		Cubage assembled 700 cu. ft.		217
Pneumatic tool set No. 1	1		1						
Pump, asphalt, trailer-mounted, with distributor attachments	1		1	3.37 (engine) 1.0 (burner)	3.94	7′6″	7′0″	6′6″	218
Pump barrel, hand-operated, rotary	3	1	6						
Pump, centrifugal, gasoline-engine-driven, base-mounted, 2-in. discharge, 166 gpm, 25-ft. head	1	1	4	.64	.235	2′11″	1′10″	2′4″	219
Pump, sump, pneumatic, 3-in. discharge, 175 gpm, 25-ft. head	1		1						220
Pump, diaphragm, gasoline-engine-driven, mounted on two steel wheels, 4-in. discharge, 100 gpm, 10-ft. suction head		1	4	1.50	.65	4′9″	2′5″	3′3″	221

Table XXXV. Organic equipment, engineer aviation battalion.—Continued.*

Pump, water, trailer-mounted, with distributor attachments	1		1	1.5	2.16	15′	6′6″	6′1″	222
Rake, asphalt, 14-teeth	12	12	48		.005	5′	1′5″		
Roller, road, towed-type, wheeled, rubber-tired, 13 tires	2		2		3.5 empty	14′7″	7′4″	3′10″	223
Roller, road, towed-type, sheepsfoot, two-drum in-line		1	3		6.04 empty	14′7″	9′7″	4′10″	224
Rooter, road, cable-operated, three-tooth	1		1		7.5	17′0″	8′4″	5′7″	225
Saw, chain, portable, gasoline-engine-driven, 36-inch blade		2	6						226
Scraper, road, towed, cable-operated, 8-cu.-yd.	1	2	7		14.0 empty	29′7″	9′10″	9′11″	227
Sharpener, chain, saw, gasoline-engine-driven	1		1						
Sweeper, rotary-broom, tractor-mounted and powered, one-way sweeping, 30-in. by 7-ft. brush	1		1		.86 brush only				228
Surveying equipment, set No. 6, general-purpose	2		2						
Tank, asphalt, steel, trailer-mounted, with steam coils, 1,500-gal.	2		2		10.0 empty	20′0″	8′0″	9′6″	229
Semi-trailer, low-bed, with dolly, 20-ton	5	3	14		16.7 net 56.7 gross	39′9″	8′6″	5′7½″	230
Tractor, device, grouse type									
Water-supply equipment, set No. 1, engineer	1		1						231

Table XXXV. Organic equipment, engineer aviation battalion.—Continued.*

Item	Units available			Hourly fuel consumption (gallons)	Weight loaded (1,000 lb.)	Dimensions			Figure number
	Headquarters and headquarters company	Com-pany	Total			Length	Width	Height	
Water-purification unit, pack, with hand- and gasoline-engine-driven pump, 150-gph.		1	3						
Welding equipment:									
Set No. 1, electric-arc, gasoline-engine-driven, 300-a., trailer-mounted	1		1						232
Set No. 2, oxyacetylene		1	3						233
Engineer issue, motorized									
Crane, truck-mounted, gasoline-engine-driven, ⅜-cu. yd., complete	1		1	2.0	13.1 net 26.4 gross	59'0"	8'0"	10'8"	234
Compressor, air, truck-mounted, gasoline-engine-driven, 105-cfm.		1	3	2.5	14.3 gross	21'4"	7'8"	8'0"	235
Ditching machine, ladder-type crawler-mounted, gasoline-engine-driven, digging depth 8-ft., width 18- to 24-in.	1		1	6.0	23.0	17'9" 24'6"	*Working* 11'0" *Transport* 7'8"	15'11" 10'6"	236
Grader, road, motorized, diesel-engine-driven, 12-ft. moldboard	5	1	8	2.25 (½ load)		25'2"	8'0"	10'0"	237
Roller, road, gasoline-engine-driven, tandem, two-axle, 5- to 8-ton	2		2	2.0	17.63	14'4"	5'3"	7'2"	238
Roller, road, gasoline-engine-driven, tandem, three-wheel, 10-ton	1		1	2.5 to 3.25	20.05	17'3"	6'4"	10'0"	239

Table XXXV. Organic equipment, engineer aviation battalion.—Continued.*

Scraper, road, motorized, towed, cable-operated, 12-cu. yd.	3		3		30.5 empty	32′2″	10′2″	11′2″	240
Shop equipment, 3rd-echelon, motorized: Set No. 2, emergency repair	1		1						241
Set No. 3, general purpose	1		1						242
Set No. 4, machine shop, heavy	1		1						243
Set No. 9, welding	1		1						244
Power plant, 5-kw, trailer-mounted	1		1						245
Shovel, crawler-mounted, gasoline-engine-driven, ¾-cu. yd. with attachments	2		2						246
Tractor, crawler type, Diesel-engine-driven, 70 to 90 DBHP, with angledozer	2	3	11	4.38	32.9	16′2″	8′0″	9′0″	247
Tractor, wheeled, rubber-tired, gasoline-engine-driven, 30 DBHP.	2		2	3.35	5.12	9′6″	5′4″	5′4″	248
Ordnance issue, vehicle									
Trailer, two-wheel, ¼-ton	4	4	16		.55 net 1.05 gross	6′6″		3′6″	
Trailer, water-tank, 250-gal., 1-ton, two-wheel	2	2	8		1.4 net 3.4 gross	11′5″	5′11″	4′10″	
Trailer, cargo, 1-ton, two-wheel	6	4	18		1.47 net 3.47 gross	12′2″	5′11″	6′1″	
Truck, ¼-ton, 4 x 4	4	4	16		2.45 net 3.25 gross	11′0″	5′2″	4′4″	
Truck, wrecker, 4-ton, 6 x 6, complete with equipment	1		1		21.7 gross	24′4″	8′5″	9′3″	

Table XXXV. Organic equipment, engineer aviation battalion.—Continued.*

Item	Units available			Hourly fuel consumption (gallons)	Weight loaded (1,000 lb.)	Dimensions			Figure number
	Headquarters and headquarters company	Company	Total			Length	Width	Height	
Truck, cargo, 2½-ton, 6 x 6, w/o winch	2	2	8		10.1 net 15.1 gross	20′5″	7′4″	9′2″	
Truck, tank-gasoline, 750-gal., 2½-ton, 6 x 6	1		1		11.6 net 16.1 gross	21′2″	7′7″	8′0″	
Truck, dump, 2½-ton, 6 x 6 w/winch	10	9	37		11.9 net 16.9 gross	22′9″	7′4″	8′4″	
Truck, dump, 4-ton, 6 x 6, w/o/winch	5	3	14		17.5 net 26.4 gross	21′3″	7′10″	8′11″	
Truck, command, ¾-ton, 4 x 4	1	1	4		5.4 net 6.9 gross	14′8″	6′7″	6′10″	
Truck, weapon, carrier, ¾-ton, 4 x 4, w/o/-winch	4	1	7		5.6 net 7.1 gross	13′11″	6′11″	6′9″	
Truck, prime-mover, 6-ton, 6 x 6 w/winch	6		6		22.1 net 34.1 gross	24′0″	8′0″	9′5″	
Signal issue Convertor, M209 or cipher device M94	1								
Detector set, SCR-625 (antitank mine portable)	3	3	12						
Flashlight, TL-122	36	20	96						
Frequency meter, set, SCR-211	1								

Table XXXV. Organic equipment, engineer aviation battalion.—Continued.*

Holder, M–167	2	1	5						
Loudspeaker, LS–3	1								
Photographic equipment, Ph-383, regimental	1								
Radio, set, SCR–193	1								
Radio, set, SCR–284	1	1	4						
Reel, cart, RL–35 (or RL–16)	1								
Reel, unit, RL–31	1								
Switchboard, BD–71	1								
Switchboard, BD–72	1								
Telephone, EE–84A	16								
Terminal strip, TM–184	2								
Tool, equipment, TE–33	1								
Wire, 110–B, 10% on reel DR–4 and 90% on DR–5, miles	6								
Ordnance issue—Medical section: Ambulance, ¾-ton, 4 x 4			1		5.9 net 7.7 gross	16′3″	6′6″	7′6″	
Defroster, and de-icer windshield, electric			3						
Truck, ¼-ton, 4 x 4			1						
Truck, cargo, 2 ½-ton, 6 x 6			1						
Signal issue: Flashlight, TL–122			17						

* New proposed Table of Equipment.

*Table XXXVI. Equipment data, airborne engineer aviation battalion.**

Item	Length (in.)	Width (in.)	Height (in.)	Vol. (cu. ft.)	Weight (lb.)	Per hq. co.	Per co.	Med. sect.	Total bn.	Figure No.
Engineer issue										
Blacksmith equipment, engineer	21	9	10	1.1	100	1	—	—	1	
Carpenter equipment, squad	64	16	17	9.5	60	1	2	—	7	
Compressor, air, trailer-mounted, pneumatic tires, engine-driven, 60 cfm	72	31 ½	52	63.0	1,290	2	2	—	8	249
Cylinder, oxygen	57	9 Dia.		2.1	270	4	2	—	10	
Demolition equipment, squad	40	16	18	8.24	85	1	2	—	7	
Drafting and duplicating equipment	26	20	10	3.1	78	1	—	—	1	
Electric lighting set	28	19	21	6.13	79	3	1	—	6	
Grader, road, towed-type, leaning-wheel, hand-controlled, 6 ½-ft. moldboard	174	70	63	444.06	1,820	1	2	—	7	250
Kettle, asphalt-repair, trailer-mounted, with motor-driven hand spray, 110-gallon-capacity	113	51	48	160.0	1,280	3	—	—	3	251
Loader, aggregate, bucket, tractor-mounting, bucket only, front-end, hydraulic operated, 1/3-cu. yd	93	36	33	70.0	1,100	2	—	—	2	252
Mixer, rotary tiller, soil-stabilization, power-take-off, trailer-mounted	128	60	51	226.6	1,050	2	—	—	2	253
Pioneer equipment, squad	64	16	17	9.5	300	1	2	—	7	
Pipe fitting equipment	26	20	10	3.0	100	1	1	—	4	
Roller, road, towed-type, smooth-drum, 5-ton water load	162	57	59	315.3	2,010	1	—	—	1	254
Roller, road, towed, sheep's-foot, single drum, with removable teeth	132	60	60	275.0	3,120	—	1	—	3	255
Rooter, road, lever-operated, three-tooth	90	60	48	150.0	700	1	—	—	1	256
Saw, chain (timber), gasoline-engine-driven	88	26	20	26.5	100	3	—	—	3	
Scraper, road towed type, hydraulically-operated, 1 ½ cu. yd	147	65	43	249.17	2,380	3	2	—	9	257
Tinsmith equipment	18	10	15	1.5	35	—	1	—	3	
Tractor, crawler type, gasoline-engine-driven, with hydraulic controls, bull-dozer, and winch, 20-DBHP	110	49	62	193.5	4,200	4	5	—	19	258
Tractor, (wheeled), rubber-tired, gasoline-engine-driven, with hydraulic controls, 23-DBHP	123	56	52 ½	208.8	3,310	4	3	—	13	252
Trailer, dump, 2-wheel, ½-ton	92	55	48	140.3	590	5	4	—	17	259
Welding equipment, electric arc	90	39	55	137.5	1,800	1	—	—	1	

Table XXXVI. Equipment data, airborne engineer aviation battalion.—Continued.*

Ordnance issue									
Launcher, rocket	4	8	4	0.9	17	8	8	—	32
Ordnance issue, vehicles									
Bicycle	60	25	40	34.7	50	2	3	—	11
Dispenser, grease	41	27	29	18.6	300	1	—	—	1
Tool set, electrical mechanics	21½	9	7	2.0	50	1	1	—	4
Truck, ¼-ton	132	63	42	357.0	3,250	7	—	1	8
Quartermaster issue									
Range, field	34	23	17	7.7	195	1	1	—	4
Tool set, blacksmith	30	14	13	3.2	147	1	—	—	1
Chemical issue									
Apparatus, 3-gal. M1, decontaminating	38	12	12	2.8	18	6	6	—	24
Medical issue									
Chest, Md. No. 60	32	21	18	7.0	165	—	—	1	1
Kit, medical, officer's	9½	5	7	0.192	35	—	—	2	2
Kit, medical, NCO	9½	5	7	0.192	35	—	—	2	2
Kit, medical, private	9½	5	7	0.192	35	—	—	10	10
Kit, medical, private	9½	5	7	0.192	35	—	—	1	1
Signal issue									
Convertor M-209 or cipher device M-94	—	—	—	—	—	2	—	—	2
Detector set SCR-625 (antitank-mine, portable)	30	10	17	29.0	60	—	2	—	6
Flashlight TL-122	—	—	—	—	—	26	22	16	108
Frequency meter set SCR-211	—	—	—	—	—	1	—	—	1
Panel set:									
AP-30-C	—	—	—	—	—	2	—	—	2
AP-30-D	20	12	7	0.9	35	2	1	—	5
Photographic set PH-261	—	—	—	—	—	1	—	—	1
Radio set:									
SCR-284	43	20	17	8.4	110	1	—	—	1
SCR-511	—	—	—	—	—	3	5	—	18
Tool equipment TE-48	—	—	—	—	—	1	—	—	1

* Engineer issue October 1943; other issue 4 May 1943.

*Table XXXVII. Equipment, engineer fire fighting platoon.**

Item	Total	Figure Number
Trailer, fire pumper, two-wheel, 500 gpm, class-1000, complete with equipment	1	260
Trailer, fire crash, two-wheel, high-pressure, class 1010, or class 1020, complete with equipment	2	261
Truck, powered, fire, crash, class 125 or class 135, complete with equipment	1	262
Truck, ¼-ton, 4 x 4	1	
Truck, weapon carrier, ¾-ton, 4 x 4	1	
Truck, cargo, 1½-ton, 4 x 4, w/winch	3	

* See TM 5-315 (when published).

Table XXXVIII. Class IV heavy construction equipment.

Item	Figure number
Asphalt and soil-aggregate mixing plant, gasoline-engine-driven, 25-tons per hour:	263
Unit No. 1, mixer, pugmill, semitrailer-mounted, with dolly. .	
Unit No. 2, dryer, aggregate, semitrailer-mounted, with dolly.	
Unit No. 3, stabilizer, soil, semitrailer-mounted, with dolly.	
Unit No. 4, elevator, bucket, trailer-mounted.	
Asphalt plant, 10-unit, 80- to 150-ton per hour:	264
Unit No. 1, conveyor, transfer, gasoline-engine-driven, 24 in. by 57 ft.	
Unit No. 2, dryer, aggregate, dual-drum, travel- or central-plant, trailer-mounted, 80- to 150-ton per hour.	
Unit No. 3, elevator, aggregate, bucket, enclosed.	
Unit No. 4, finisher, asphalt, crawler-mounted, 12-ft.	
Unit No. 5, heater, asphalt, trailer-mounted, three-car, 42-hp boiler.	210
Unit No. 6, loader, bucket, crawler-mounted, gasoline-engine-driven, 3 cu. yd. per minute, 19-ft. 10-in. boom or 17-ft. 4-in. boom.	265
Unit No. 7, mixer, asphalt, Diesel-engine-driven, travel or central plant, trailer-mounted, 112- to 200-ton per hour.	265
Unit No. 8, piping, for boilers, dryer, mixer, tank, and so forth.	
Unit No. 9, pump, asphalt, trailer-mounted, with distributor attachments.	218
Unit No. 10, tank, asphalt-storage, 4,000-gallon, bolted, with steam coils.	
Concrete plant:	
Batching-plant, aggregate, three-compartment, 105-ton capacity.	266
Finisher, concrete, form-riding, 20-ft.	267
Forms, concrete, steel, 8-in. high, 10-ft. long.	
Paver, concrete, crawler-mounted, 34-cu. ft.	268
Spreader, concrete, gasoline-engine-driven, 20-ft. width.	269
Crusher, rock, jaw type, four-wheel-trailer-mounted, 7 cu. yd. per hour, gasoline-engine-driven.	270
Crushing and screening plant, gravel and rock, two units, gasoline-engine-driven, semitrailer-mounted, with dollies, 25 ton per hour:	271
Unit No. 1, primary crusher.	
Unit No. 2, secondary crusher.	
Crushing and screening plant, gravel, crawler-mounted, 100 ton per hour, gasoline-engine-driven, five-unit:	
Unit No. 1, 1st roll crusher.	
Unit No. 2, 2nd roll crusher, washer and screen.	
Unit No. 3, power unit, trailer-mounted.	
Unit No. 4, sand dehydrator.	
Unit No. 5, conveyors:	
1 50-ft. conveyor, high-mast.	
2 50-ft. conveyor, low-mast.	

Crushing, screening, and washing plant, rock, crawler-mounted, 150 ton per hour, gasoline-engine-driven, nine-unit:	272
Unit No. 1, jaw crusher.	
Unit No. 2, 1st roll crusher.	
Unit No. 3, 2nd roll crusher, washer, and screen.	
Unit No. 4, 3rd roll crusher.	
Unit No. 5, sand dehydrator.	
Unit No. 6, scrubbing and washing coarse aggregate	
Unit No. 7, power unit, trailer-mounted.	
Unit No. 8, water supply for washing aggregate.	
Unit No. 9, conveyors:	
1 35-ft. conveyor, low-mast.	
2 50-ft. conveyor, low-mast.	
1 50-ft. conveyor, high-mast.	
Auxiliary equipment:	
Floodlight, carbide, portable, 8,000-candlepower.	
Pump, centrifugal, gasoline-engine-driven, base-mounted, 2-in. discharge, 60 gallons per minute, 125-ft. head.	273
Roller, road, gasoline-engine-driven, tandem, three-axle, 9- to 14-ton.	
Roller, road, towed-type, wheeled, rubber-tired, 13 tires.	223
Shovel, crawler-mounted, Diesel-engine-driven, 2-cu. yd. with attachments.	274
Spreader, aggregate, towed, traction-powered, 8-foot wide.	275
Tank, asphalt, steel, trailer-mounted, with steam coils, 1,500-gallon.	229
Tank, water-supply, skid-mounted, 750-gallon, two-compartment.	276
Trailer, full, low-bed, 60-ton.	277
Wagon, dirt or rock, bottom-dump, 11-cu. yd. struck.	278

206. MAINTENANCE. a. General. Maintenance of equipment cannot be stressed too highly. *The battalion cannot operate unless its equipment is in working condition.* There must be continuous first-echelon and preventive maintenance by all drivers and equipment operators, frequent command inspections, periodic technical inspections, and regular and systematic second-echelon maintenance. *Some form of daily motor inspection and servicing and a thorough weekly inspection are necessary.* All personnel who are drivers, operators, mechanics, or supervisors must become thoroughly familiar with FM 25–10 and TM 38–250.

b. Five-echelon system. The primary purpose of motor maintenance is to meet military operational requirements with a minimum loss of time from avoidable repairs. The army system of maintenance is based upon the five-echelon system. Variations from this system are sometimes necessary because of special operating conditions or peculiarities of equipment, but in general it is applicable.

(1) First-echelon maintenance is preventive maintenance performed by the operator. It includes care, use, operation, cleaning, preservation, and lubrication, as well as inspection, adjustment, minor repairs, and parts replacement.

(2) Second-echelon maintenance provides additional preventive maintenance, technical advice, technical supervision, technical assistance and command, and technical inspection. It supplies the necessary tools, parts, and skill to perform operations within its scope and beyond the capabilities and facilities of the first echelon. First- and second-echelon maintenance are closely related and both are a part of "organizational maintenance"—maintenance within the unit.

(3) In third-echelon maintenance the service maintenance and supply organizations work closely with the using troops. They overhaul and replace specific subassemblies and assemblies and repair the overflow from lower echelons. They support the lower echelons by contact parties and by supply of repair parts.

(4) Fourth-echelon maintenance is service maintenance performed by an established pool of variable numbers and types of maintenance and supply units organized as a semifixed shop to serve a geographical area. It serves all forward echelons with higher degree of skill and a larger stock of parts, subassemblies, and assemblies. It sends forward contact parties or reinforcing elements as required. Its main function is rebuilding major items from serviceable assemblies and subassemblies on hand or accumulated from serviceable major items, and supplying the lower echelons.

(5) Fifth-echelon maintenance is service maintenance performed by complete reconditioning of material and by limited manufacture. This echelon is charged with supplying lower echelons, furnishing specially skilled personnel, and reclamation. Fifth-echelon establishments are located in rear areas and utilize fixed installations.

(6) Aviation engineer maintenance companies do third-echelon maintenances for aviation engineer equipment. Fourth-echelon and fifth-echelon work normally is done by heavy shop companies of ground or service forces.

c. Aviation engineer units. Since aviation engineer units frequently operate in remote areas, often they do maintenance normally performed by higher echelons. The battalion has a third-echelon motorized shop consisting of an emergency-repair set, a general-purpose set, a heavy-machine shop, a welding set, and a 5-kilowatt, trailer-mounted power plant to power these sets. This shop, with properly trained personnel, is well equipped to maintain aviation engineer items. Maintenance must be under competent supervision with precise workmanship stressed.

d. Literature. The Engineer Field Maintenance Office, P.O. Box 1679, Columbus, Ohio, can supply complete literature on care, operation, and maintenance of engineer equipment for units in the United States. Using organizations in overseas theaters should requisition engineer parts, supply, and maintenance publications in the same manner and through the same channels as used for requisitioning spare parts (fig. 202). Those of particular interest to the aviation engineers are as follows: technical manuals; lubrication guides and folders; field service bulletins; engineer maintenance circulars, EMC–2020 series; equipment data books; export manuals; reference library on shop practices; ASF Engineer Supply Catalog; and the Maintenance Engineer.

e. Spare parts. Standard nomenclature lists are available to all arms and services. These lists are included in Part III of the Engineer Supply Catalog and also in the maintenance manual and parts manual issued with each item of equipment. Each battalion should have copies of these manuals, which are obtained from the Engineer Field Maintenance Office. A standard nomenclature list is a list of parts and equipment of a major item or major combinations and is used in requisitioning, storage, and issue of materiel. It provides a system of uniform nomenclature, including references to common parts. It also indicates the tools and spare parts furnished all echelons. Maintenance parts and supplies are furnished automatically in balanced depot stocks when organizations are sent overseas. Thereafter replacements are furnished upon requisition by item. Predetermined sets of spare parts and supplies accompany combat and service organizations upon departure for overseas areas. Figure 202 shows the channels through which a requisition for spare parts must pass.

207. MOVEMENT OF EQUIPMENT. a. General. The engineer aviation battalion is not motorized. All personnel can be carried in one move of all vehicles, but the prime movers must be sent back to shuttle the equipment forward. Transportation consists of personnel carriers, combat vehicles, and heavy-equipment prime movers or carriers (table XXXV). (For further information on movement see FM 101–10.)

b. Overland movement. Personnel vehicles and trucks up to the 2½-ton can move at normal convoy speeds and make long motor marches. However, prime mover equipment such as the 4-ton and 6-ton trucks move more slowly and cannot make such long marches. It is impractical to move track-laying vehicles, scrapers, the concrete mixer, and the rooter long distances overland without trailers. In practice there will be two echelons of move-

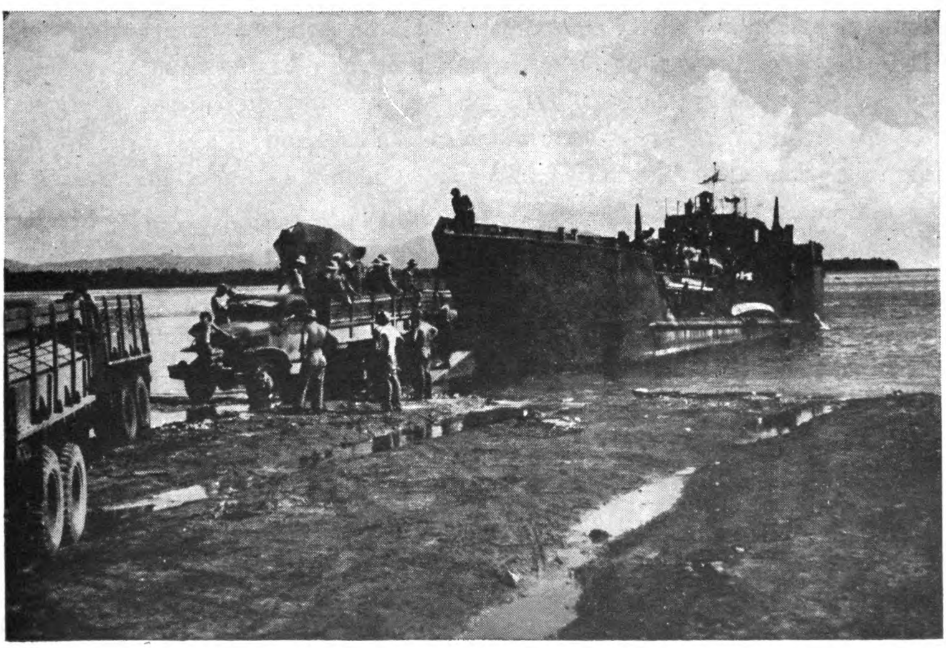


Figure 200. Landing vehicles and equipment from an LCT.

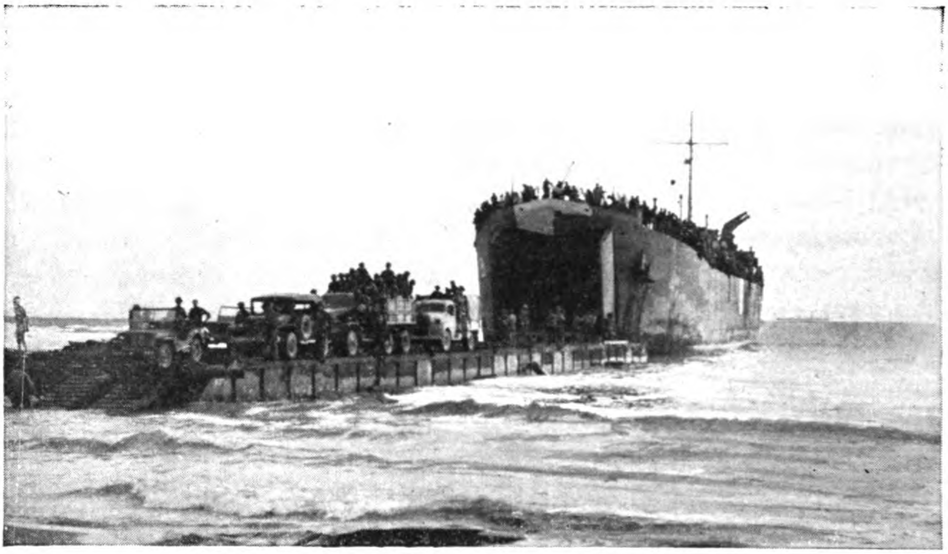


Figure 201. Landing vehicles and equipment from an LST.

ment, one to transport personnel and light equipment and the other to move heavy equipment and track-laying vehicles on trailers. Movement of heavy equipment may require two or more shuttle movements.

c. Overwater movement. In planning an overwater movement it is necessary to know the characteristics of the vessels, particularly their weight and volume capacities, hatch clearance, and machinery for handling cargo (figs. 200 and 201). It is necessary also to know weight, cubage, and dimensions of aviation engineer equipment. Data on standard vessels are given in FM 101–10. Information on other craft must be obtained from the officer in charge or by measurement. Data on weights and dimensions of aviation engineer equipment are given in tables XXXV and XXXVI. For other logistical data see tables XLVI and LII, appendix IV. For information on barging operations, see FM 5–10. For complete data on weights and cubages of engineer equipment see the bulletin, Weights and Cubages of Engineer Equipment, published by Engineer Field Maintenance Office, P.O. Box 1679, Columbus, Ohio. Other references are: FM 31–5, TM 5–9711 and TM 55–310; War Department Bulletin, Preparation for Overseas Movement (POM); and individual export manuals of instructions for preparation of engineer equipment for overseas shipment, published by Engineer Field Maintenance Office.

d. Air movement. Often it is necessary to use cargo planes to transport supplies or items of equipment not specially designed for air transport. Loading for air movement requires careful planning. The weights and dimensions of the cargo must fit the space and weight limitations of the transport

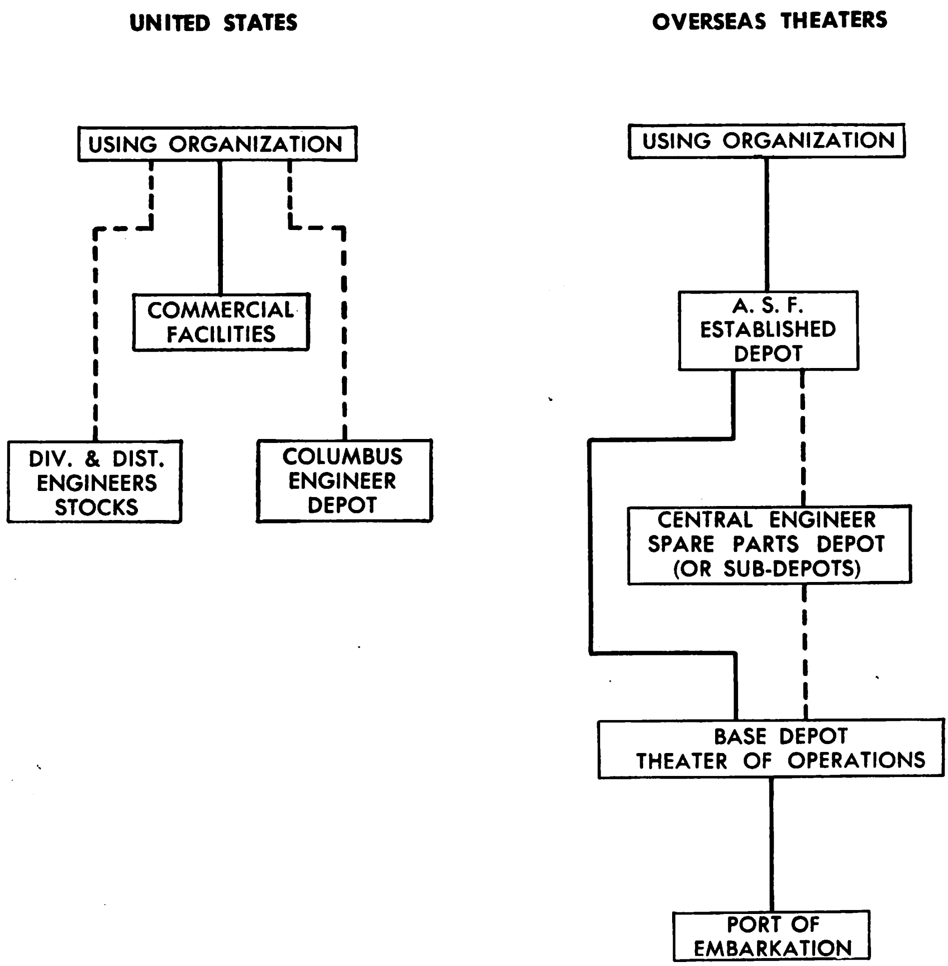


Figure 202. Requisitioning engineer spare parts.

planes. See table XLVII, appendix IV for data on cargo planes. Cargo may be grouped into three classes: small, heavy items which tax the lifting capacity of the plane; bulky but lightweight items; and bulky, heavy items. The first and second classes are combined to make use of all available cargo space without exceeding the weight capacity of the aircraft. In some cases bulk can be reduced by disassembling before loading and reassembling at destination. Some items will have dimensional limitations even after disassembly. Until standard methods of breakdown are developed improvised methods must be used where heavy equipment is transported by air. The 2½-ton truck, D–4 and D–7 tractors, graders, scrapers, and air compressors, for instance, can be transported in parts by cargo planes. Where ordinary disassembly does not satisfy weight or dimensional limitations, flame-cutting and rewelding of parts sometimes may be employed.

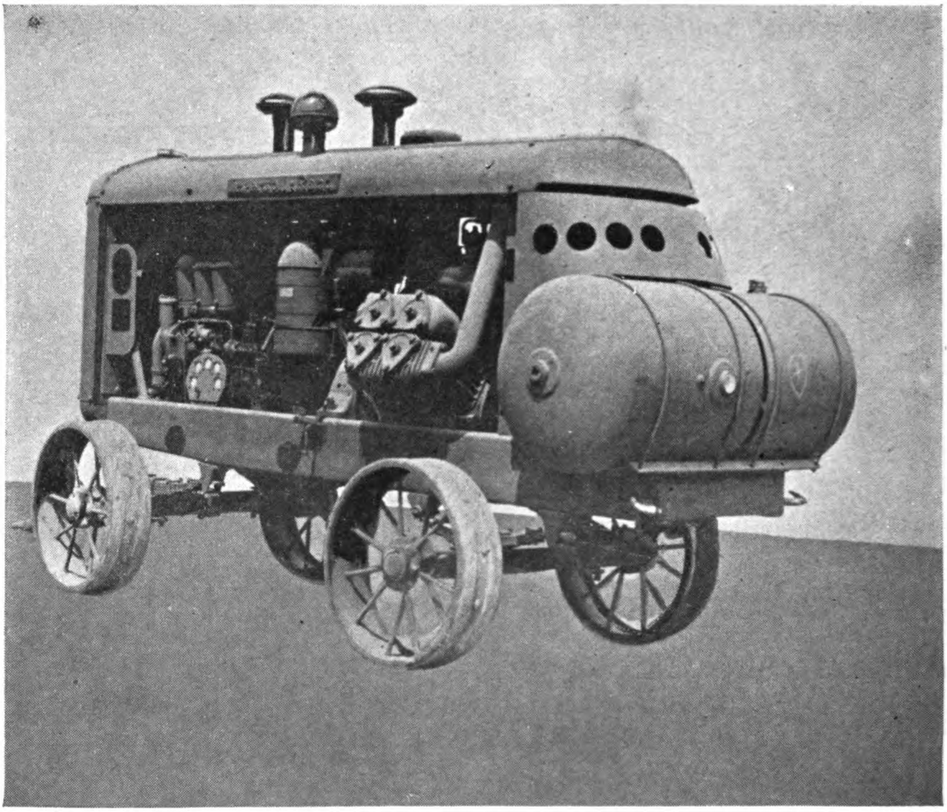


Figure 203. Compressor, air, trailer-mounted, steel wheels, Diesel-engine-driven, 315 cfm.

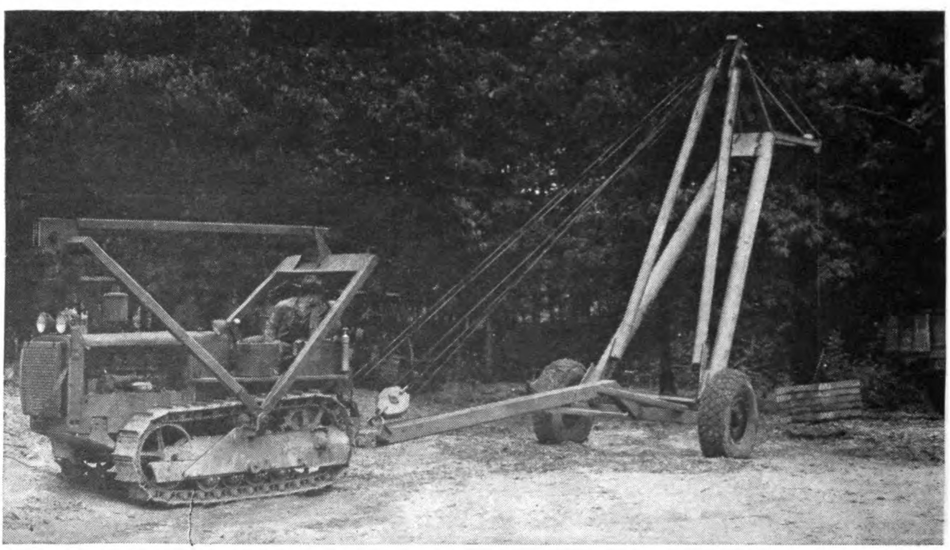


Figure 204. Crane, tractor-operated, nonrevolving, 40,000-pound capacity at 10-foot radius, 20-foot boom.

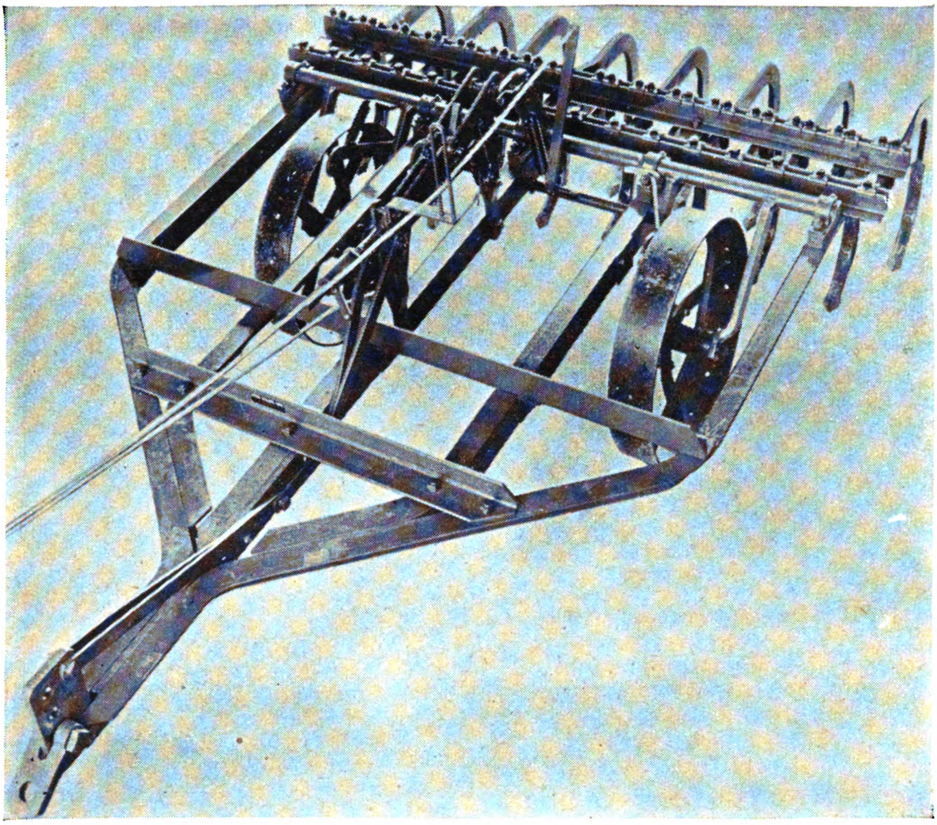


Figure 205. Cultivator, chisel-tooth, 12-inch spacing, 8-foot width.

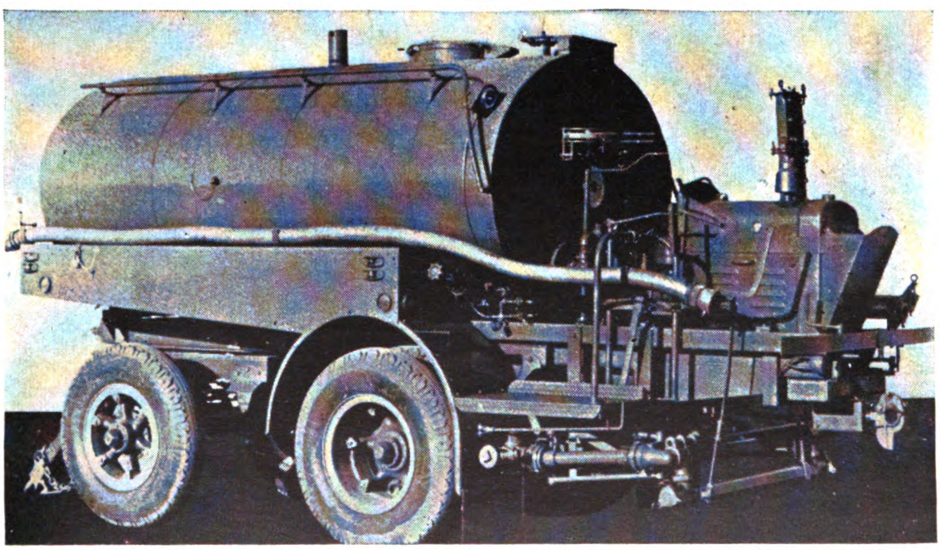


Figure 206. Distributor, bituminous materials, trailer-mounted, 1,200-gallon.

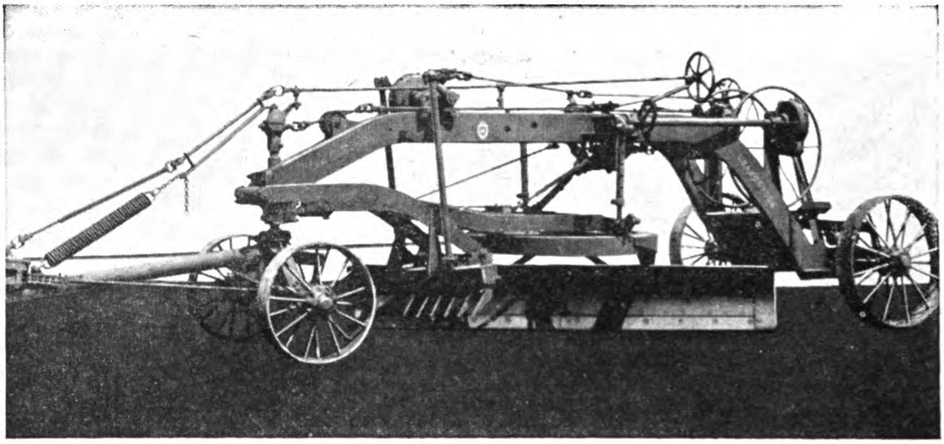


Figure 207. Grader, road, towed type, leaning-wheel, hand-controlled, 12-foot moldboard.

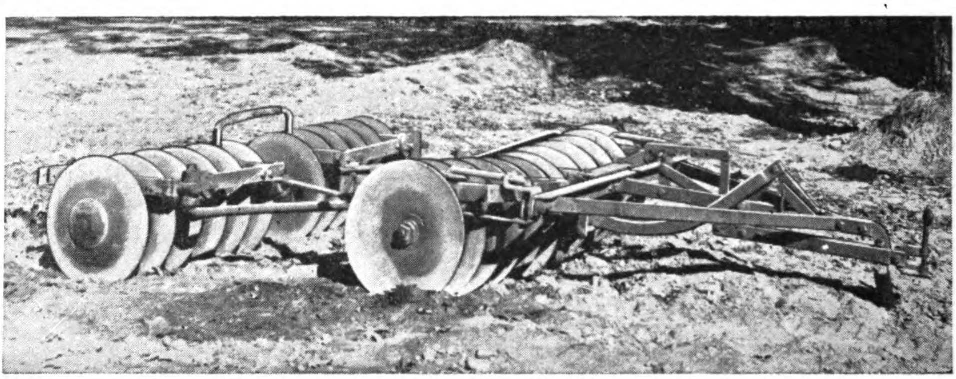


Figure 208. Harrow, disk, offset, 24-inch disks.

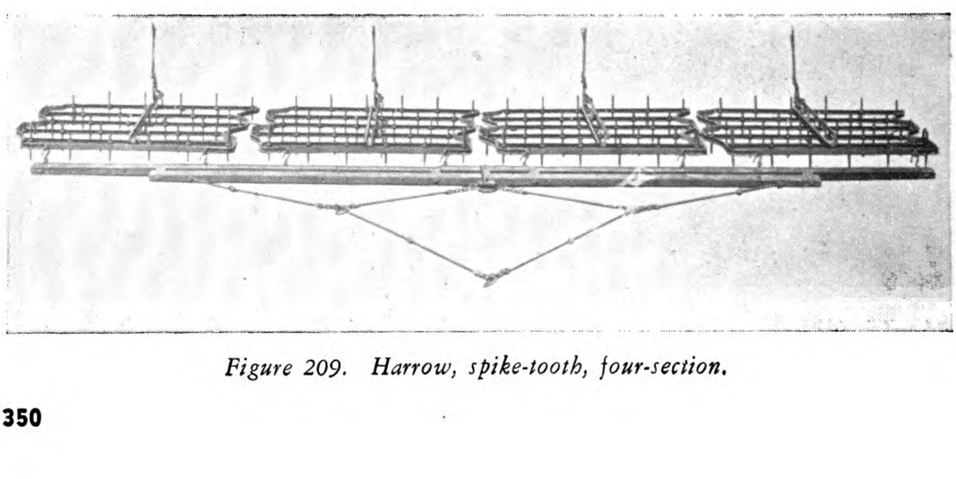


Figure 209. Harrow, spike-tooth, four-section.

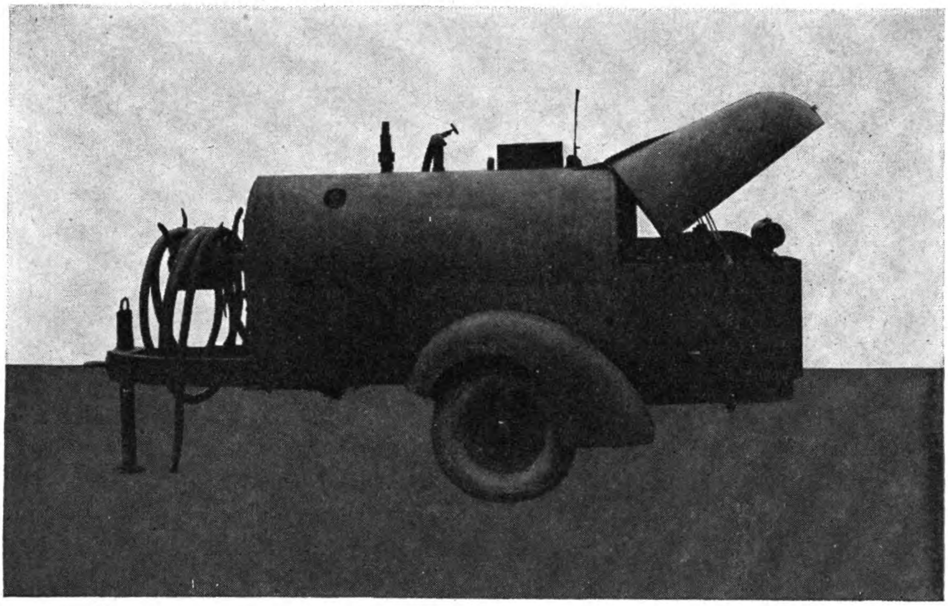


Figure 210. Heater, asphalt, trailer-mounted, three-car, 42-h.p.

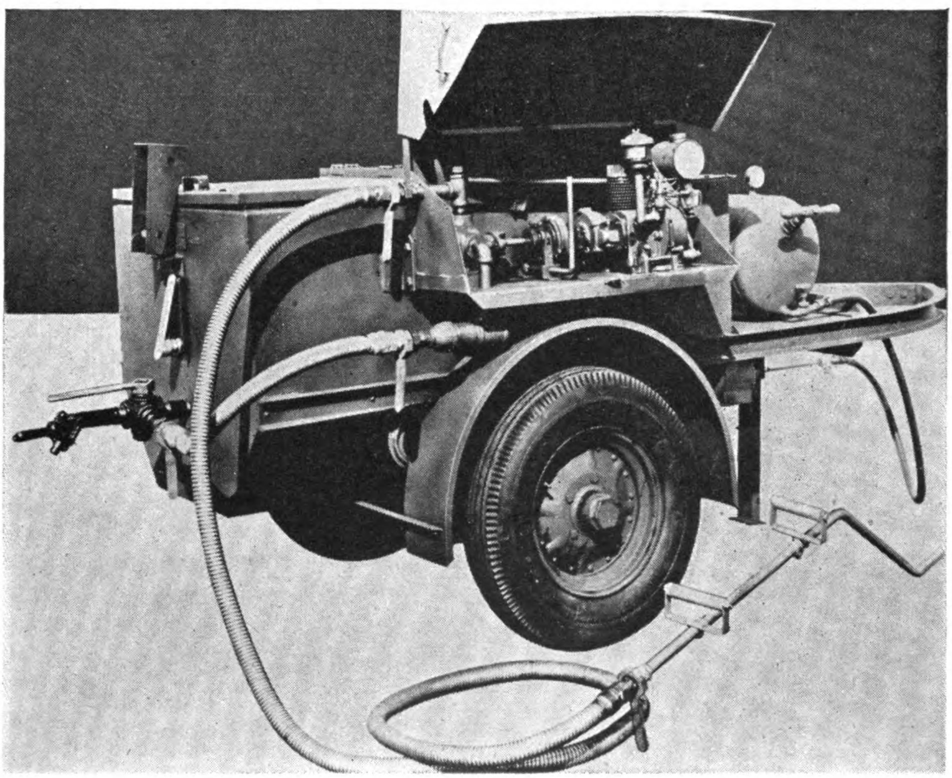
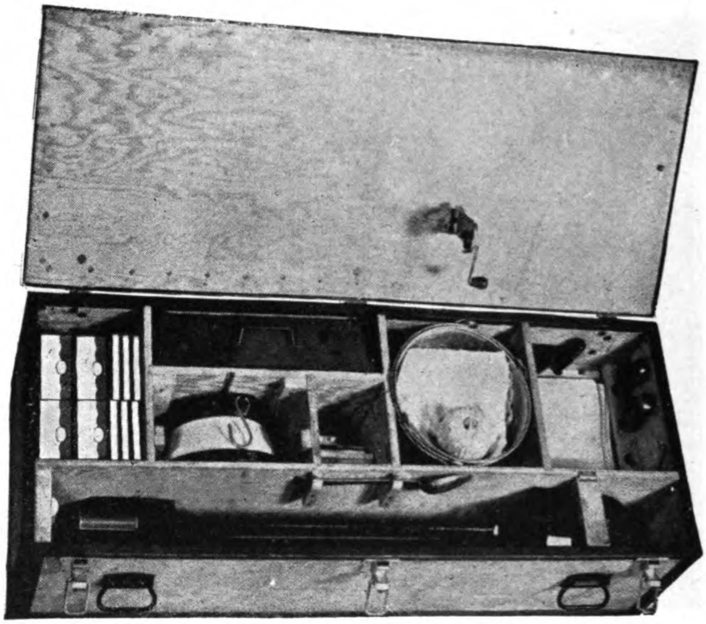
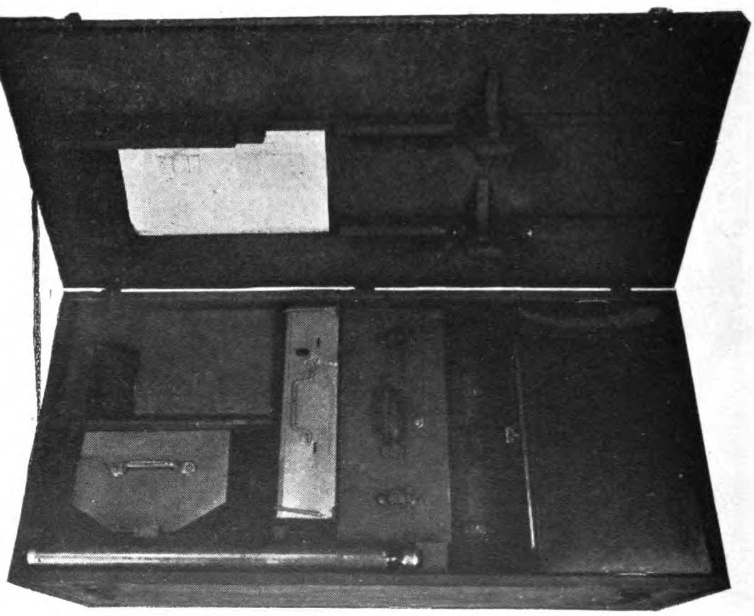


Figure 211. Kettle, asphalt-repair, trailer-mounted, with motor-driven hand spray, 165-gallon capacity.



① *Sampling equipment.*



② *Soils testing equipment.*

Figure 212. Laboratory, soil-testing, set No. 1, aviation battalion.

③ *California bearing ratio equipment.*

Figure 212. Continued.

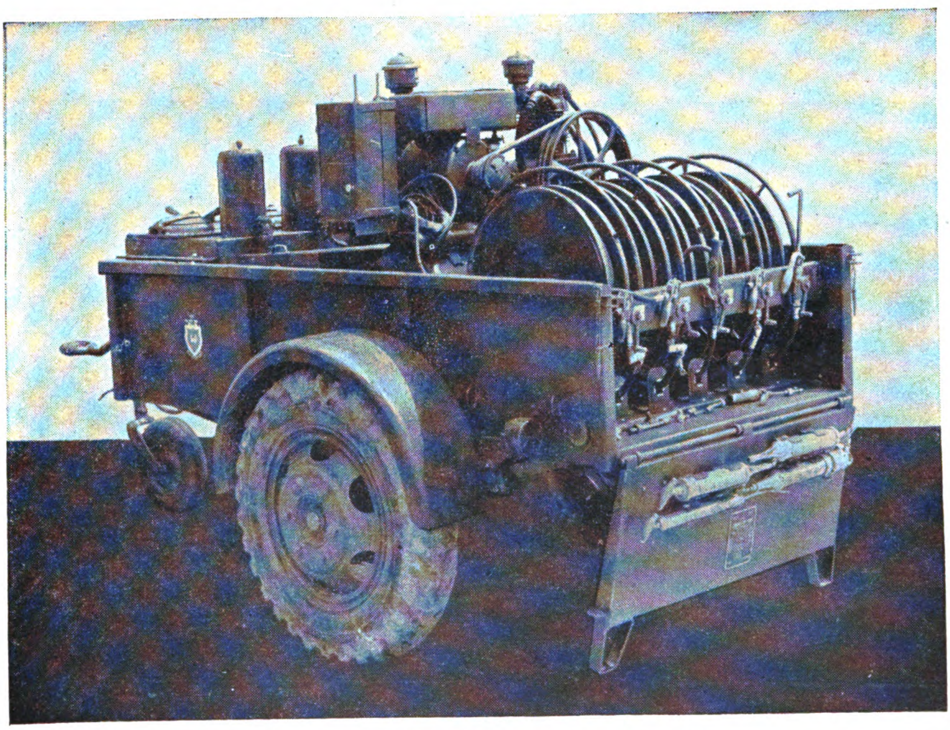


Figure 213. Lubricator, trailer-mounted.

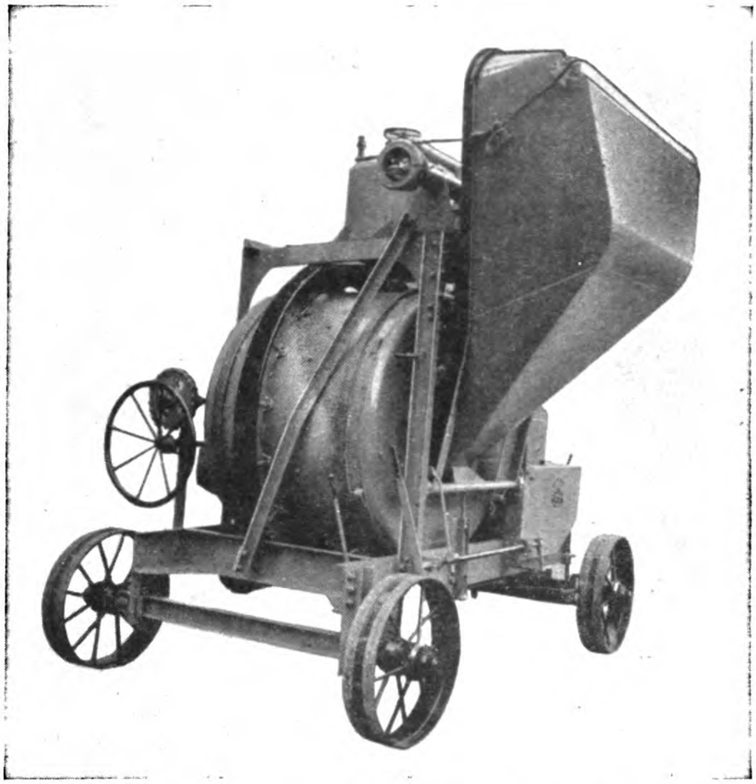


Figure 214. Mixer, concrete, gasoline-engine-driven, trailer-mounted, 14-cubic foot.

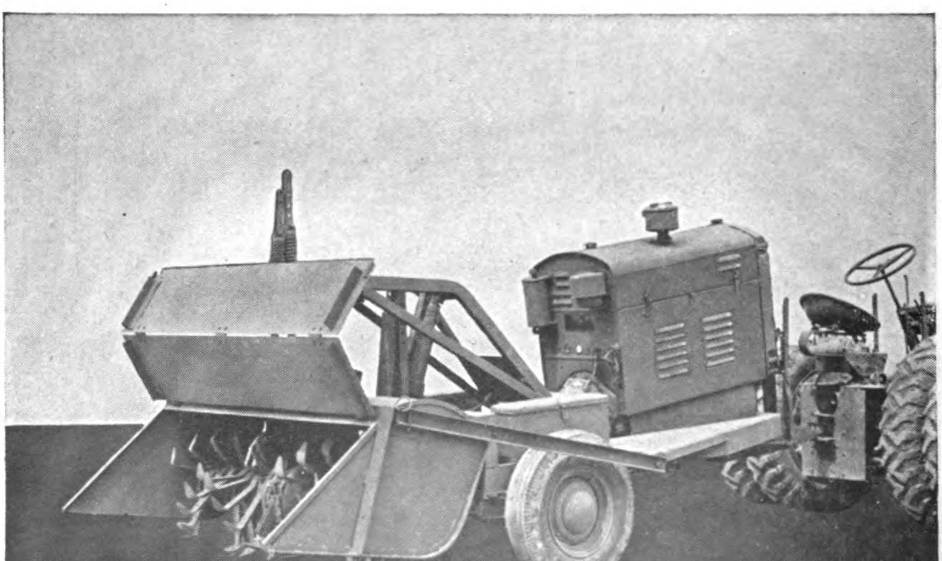


Figure 215. Mixer, rotary-tiller, soil-stabilization, gasoline-engine-driven, self-powered, trailer-mounted.

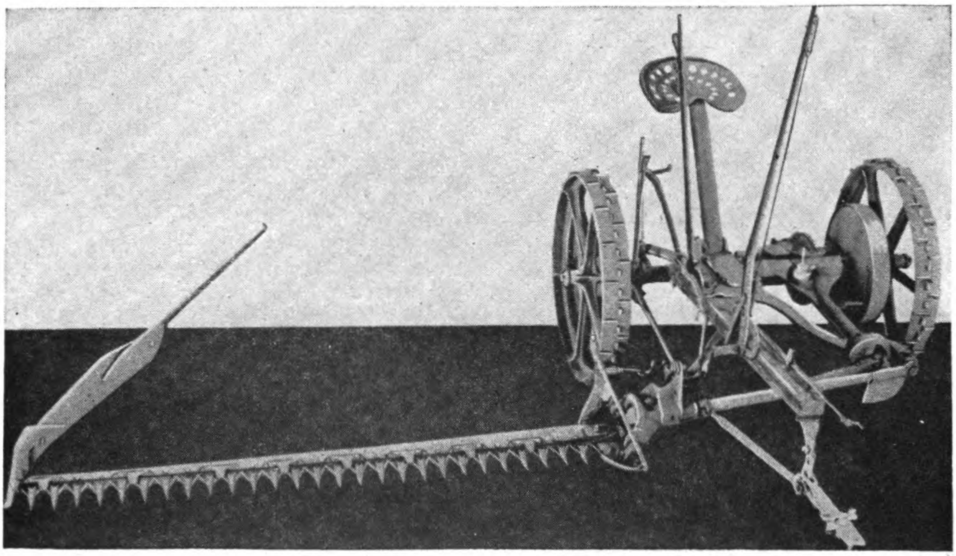


Figure 216. Mower, tractor-drawn, cutter-bar type, steel-tired, 7-foot cutter bar.

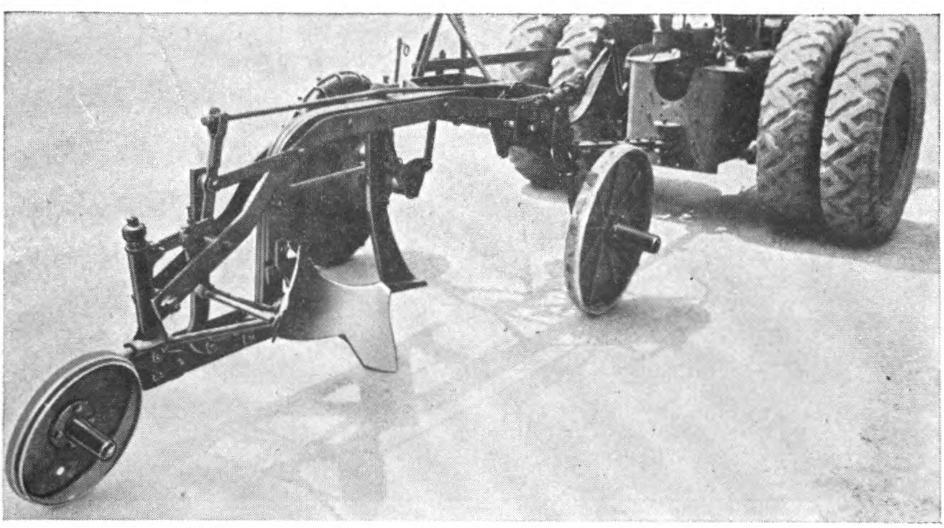


Figure 217. Plow, tractor, with standing cutter and single-plane share.

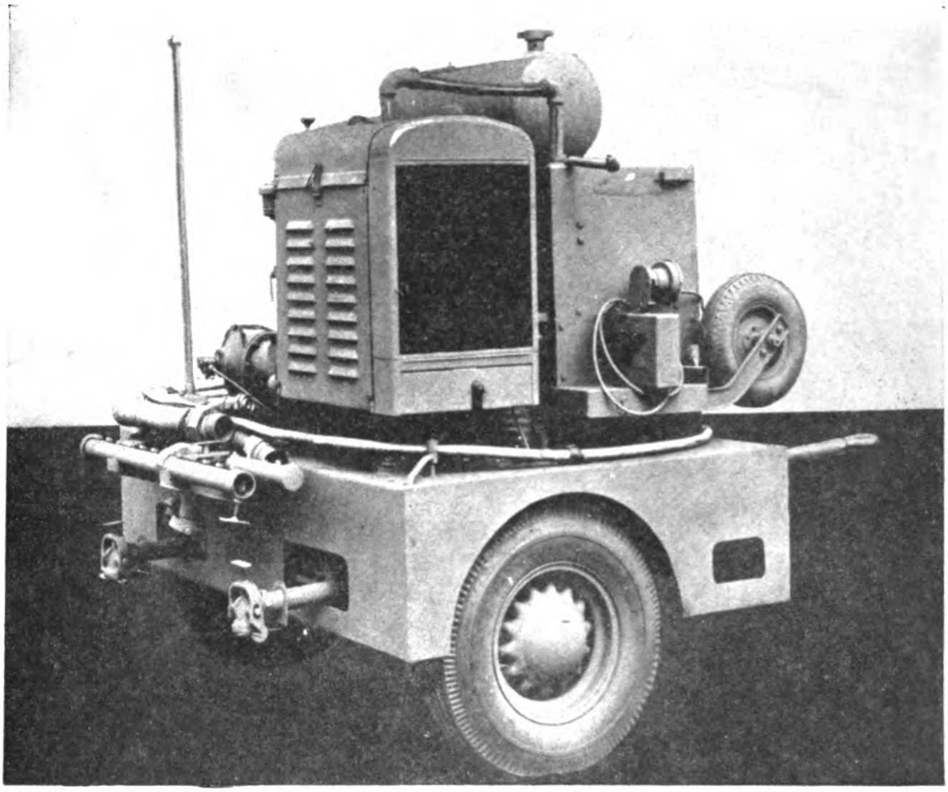


Figure 218. Pump, asphalt, trailer-mounted, with distributor attachments.

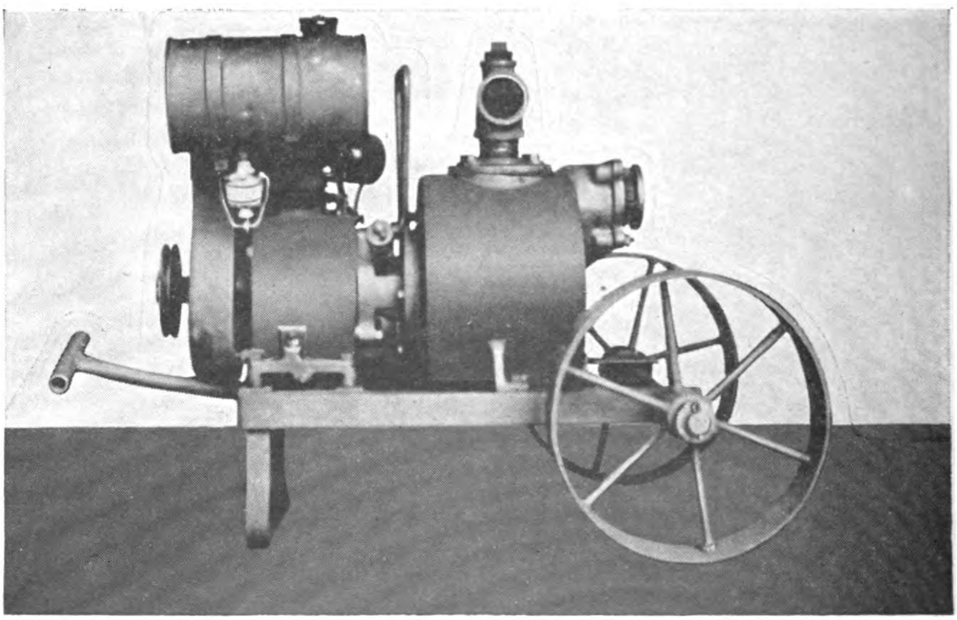


Figure 219. Pump, centrifugal, gasoline-engine-driven, base-mounted, 2-inch discharge, 166 gallons per minute, 25-foot head.

Figure 220. Pump, sump, pneumatic, 3-inch discharge, 175 gallons per minute, 25-foot head.

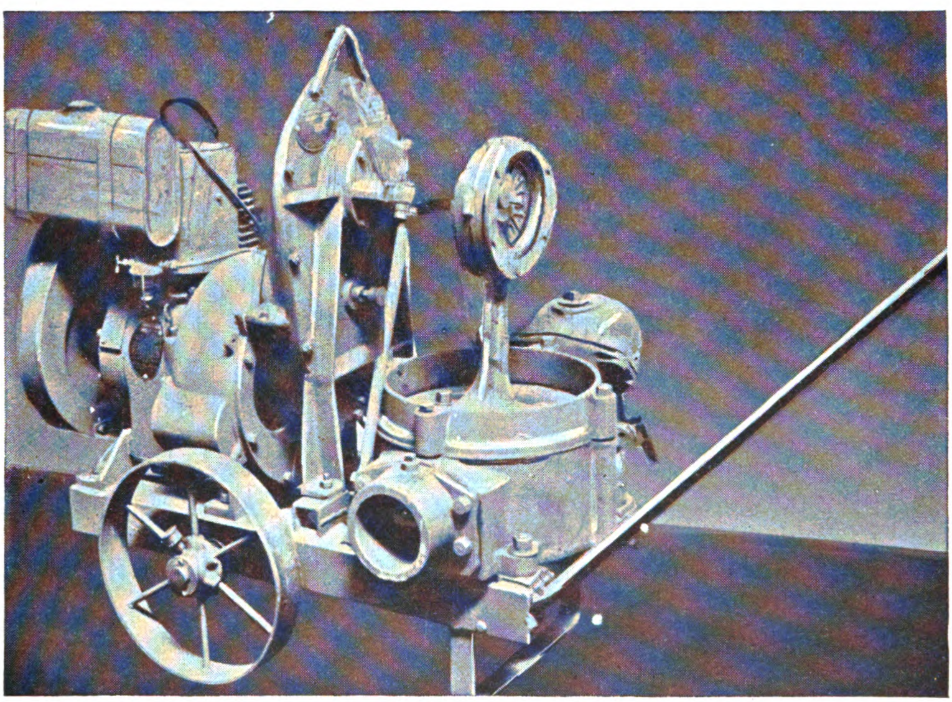


Figure 221. Pump, diaphragm, gasoline-engine-driven, mounted on two steel wheels, 4-inch discharge, 100 gallons per minute, 10-foot suction head.

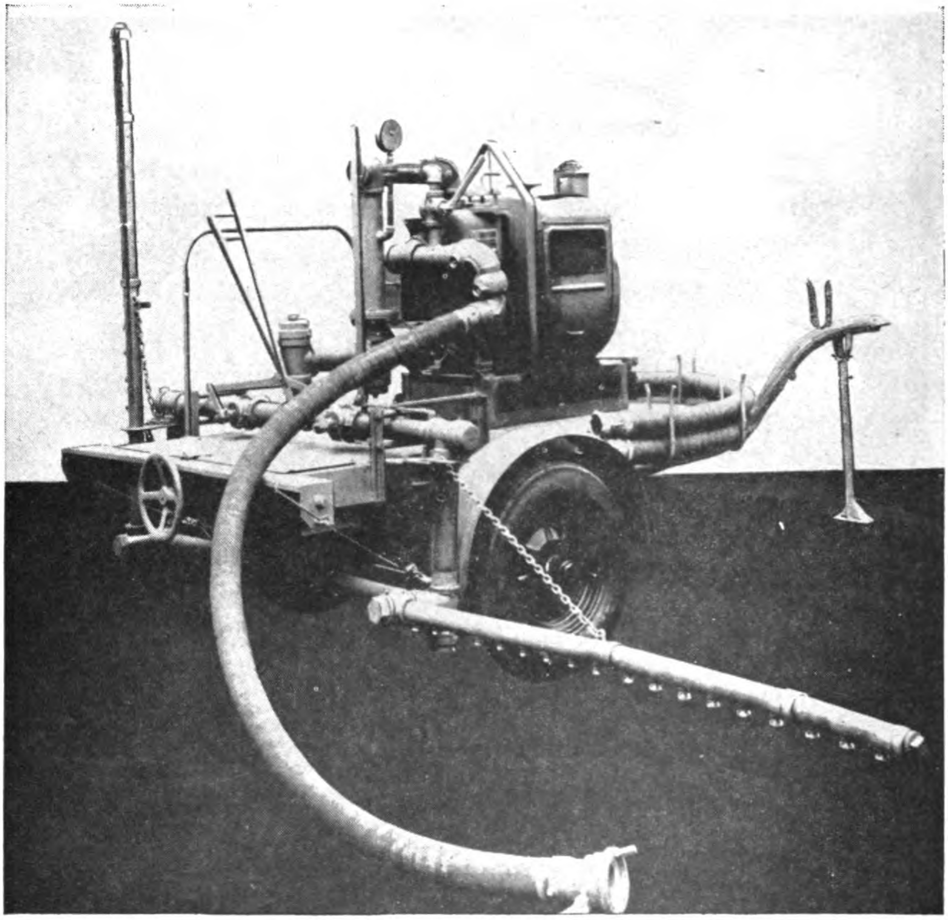


Figure 222. Pump, water, trailer-mounted, with distributor attachments.

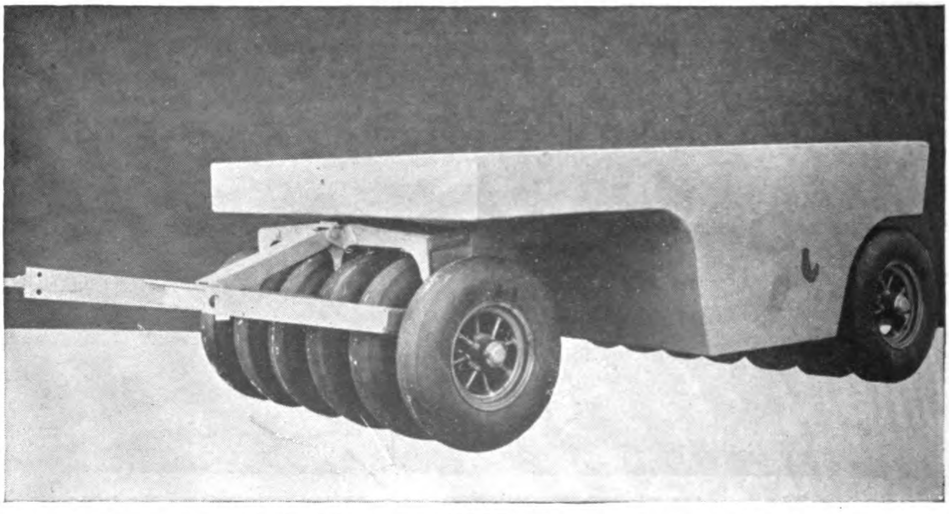


Figure 223. Roller, road, towed type, wheeled, rubber-tired, 13 tires.

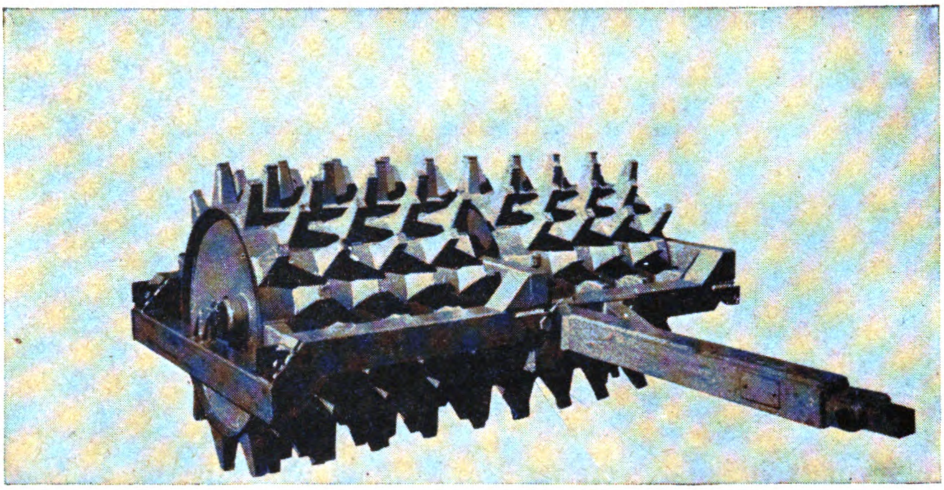


Figure 224. Roller, road, towed type, sheepsfoot, two drum in line.

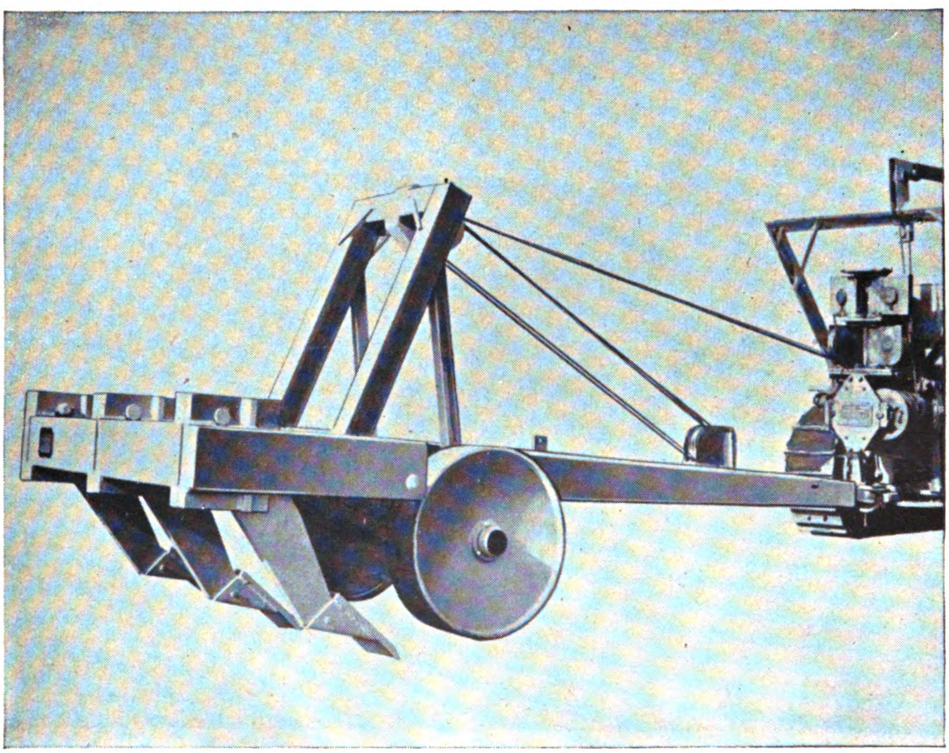


Figure 225. Rooter, road, cable-operated, three-tooth.

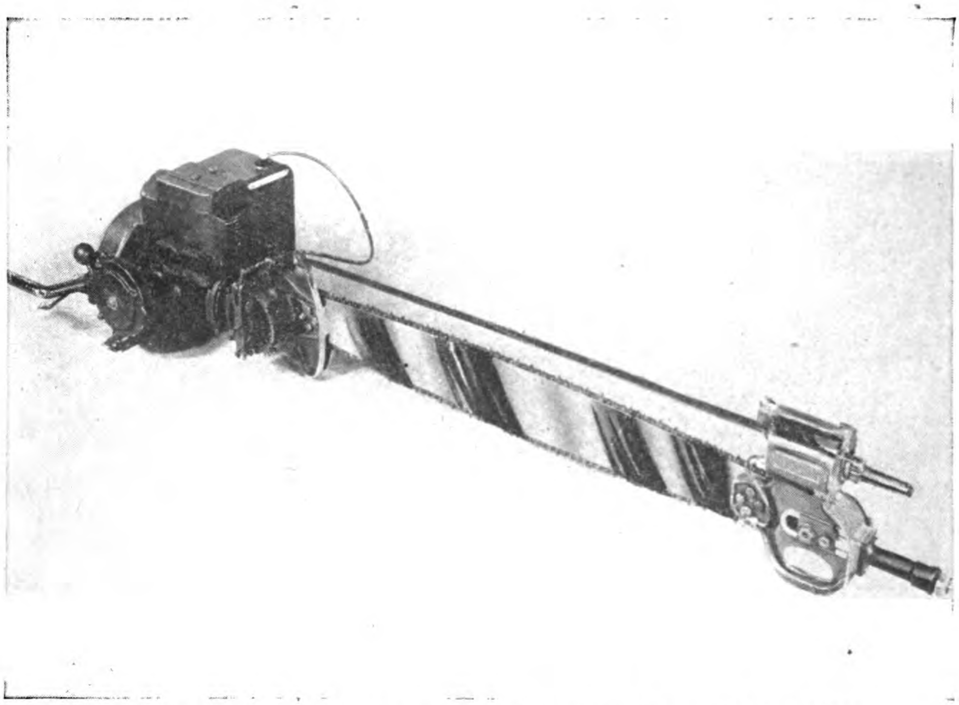


Figure 226. Saw, chain, portable, gasoline-engine-driven, 36-inch blade.

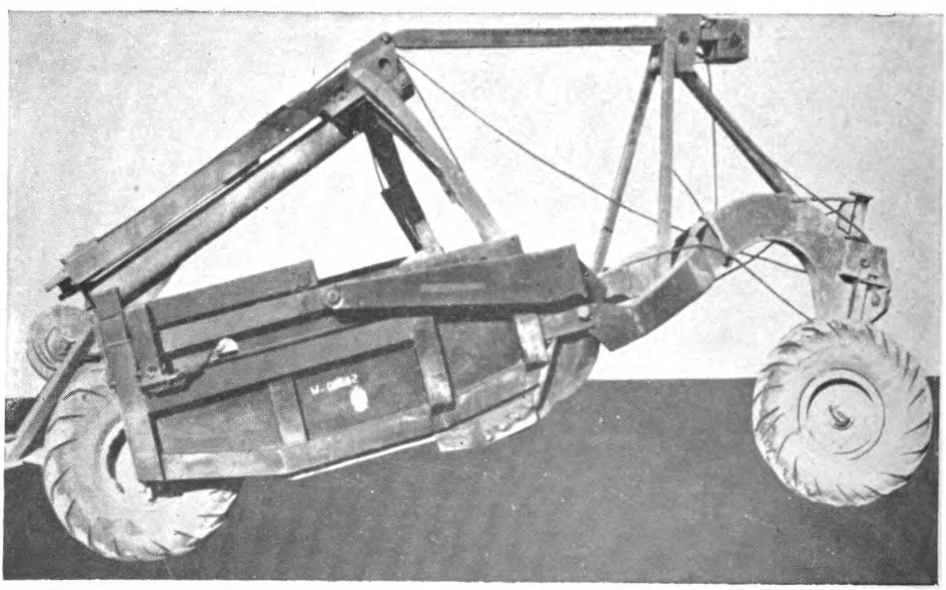


Figure 227. Scraper, road, towed, cable-operated, 8-cubic-yard.

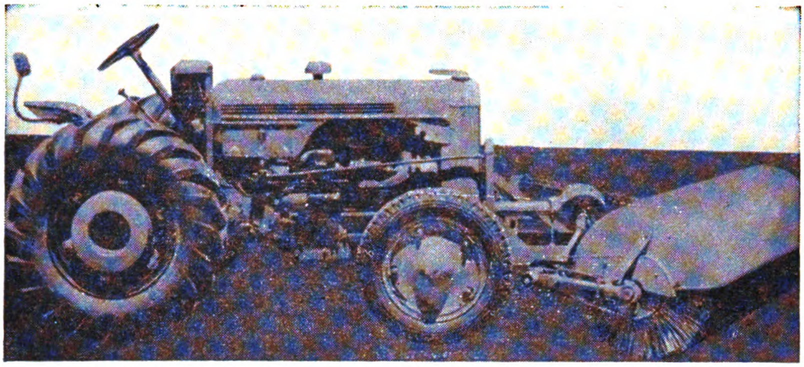


Figure 228. Sweeper, rotary-broom, tractor-mounted and powered, one-way-sweeping, 30-inch by 7-foot brush.

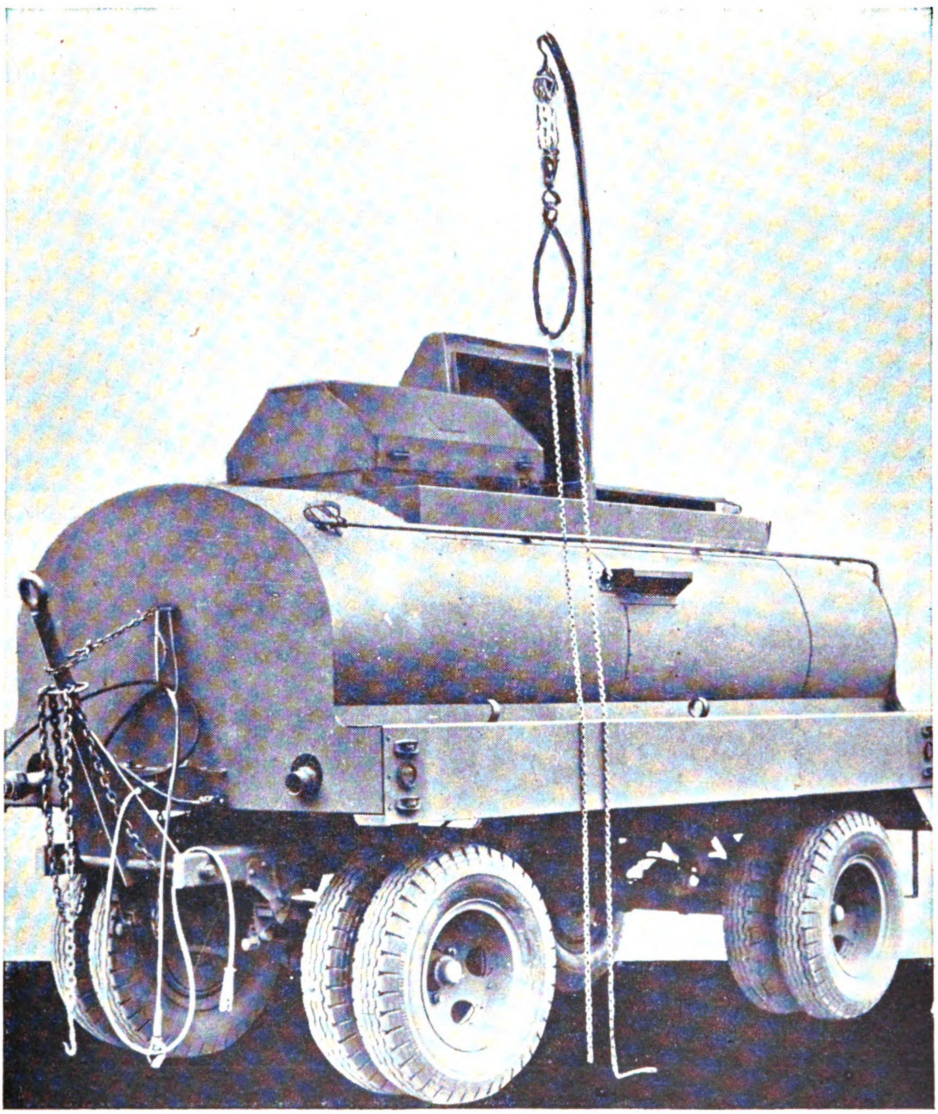


Figure 229. Tank, asphalt, steel, trailer-mounted, with steam coils, 1,500-gallon.

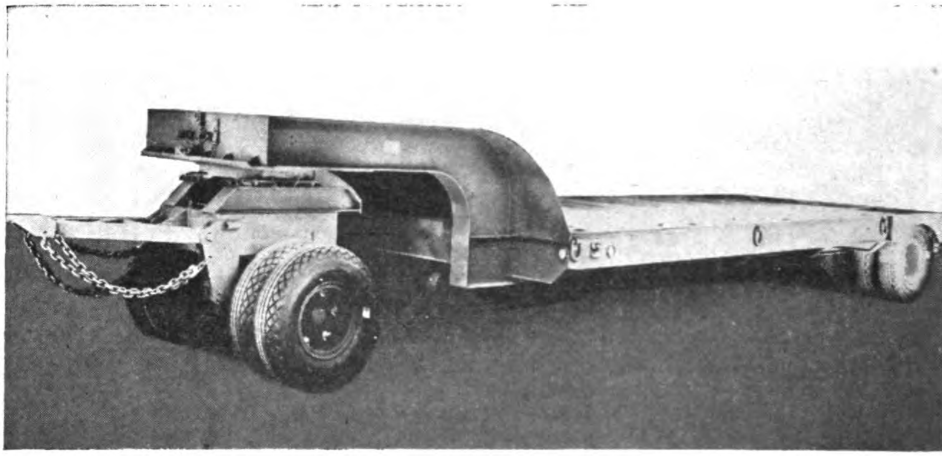


Figure 230. Semitrailer, low-bed, with dolly, 20-ton.

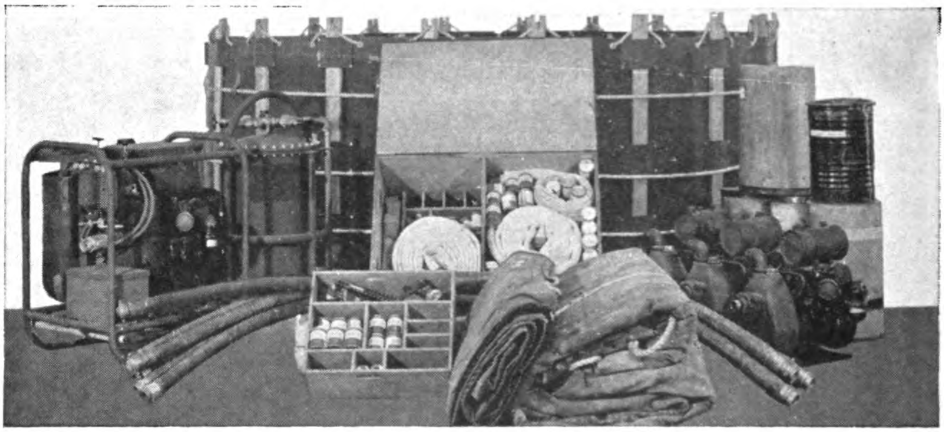


Figure 231. Water supply equipment, set No. 1, engineer.

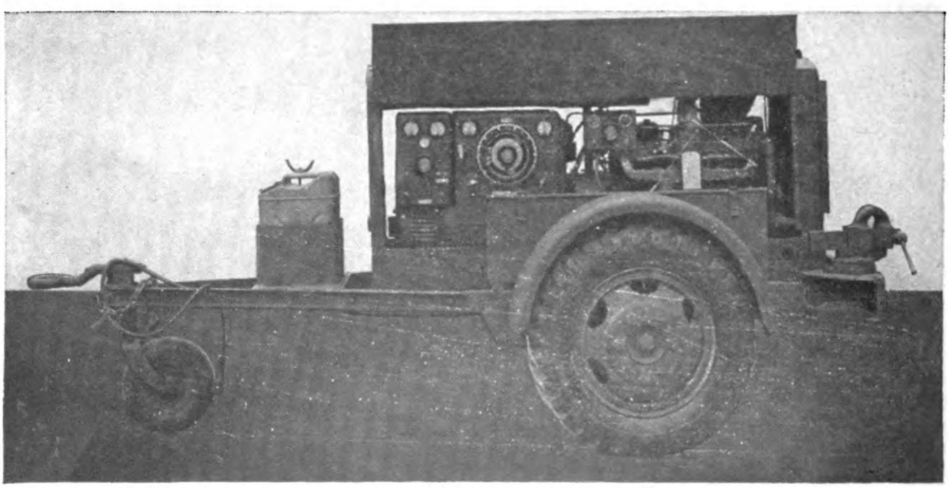


Figure 232. Welding equipment: set No. 1, electric-arc, gasoline-engine-driven, 300-ampere, trailer-mounted.

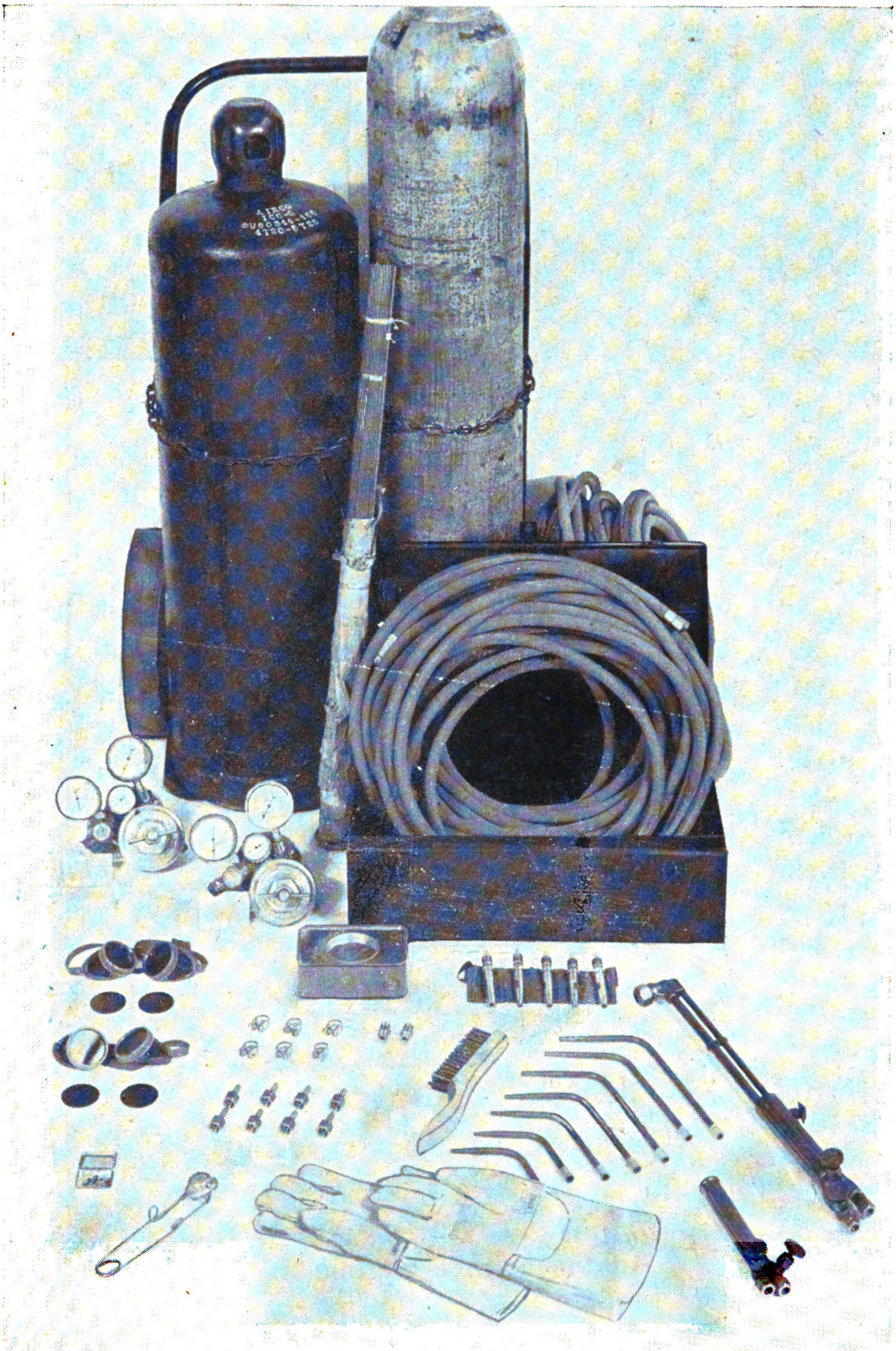


Figure 233. Welding equipment: set No. 2, oxyacetylene.

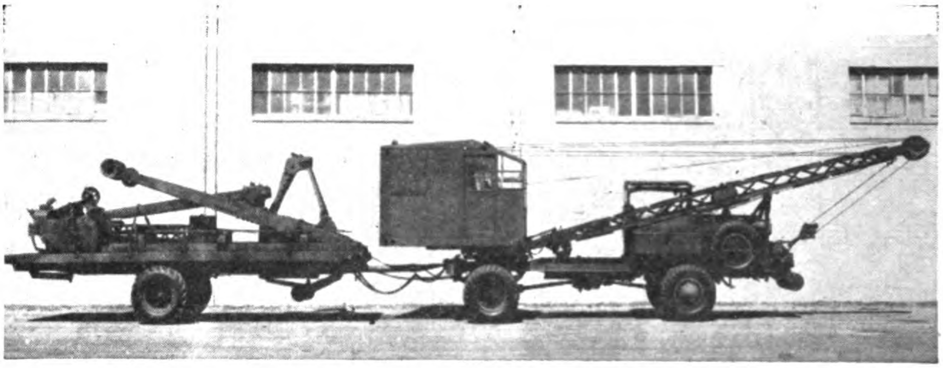


Figure 234. Crane, truck-mounted, gasoline-engine-driven, 3/8-cubic-yard, complete.

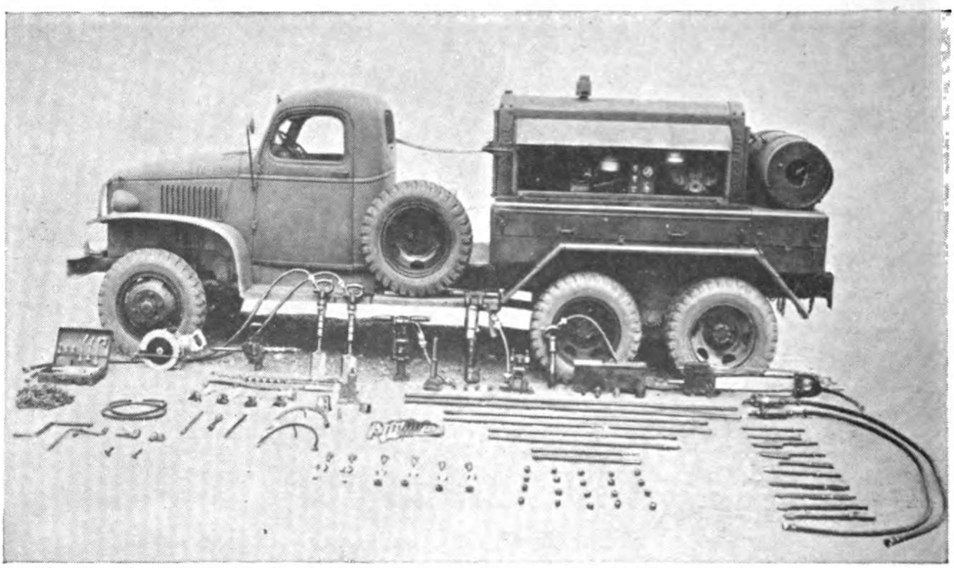


Figure 235. Compressor, air, truck-mounted, gasoline-engine-driven, 105-cfm.

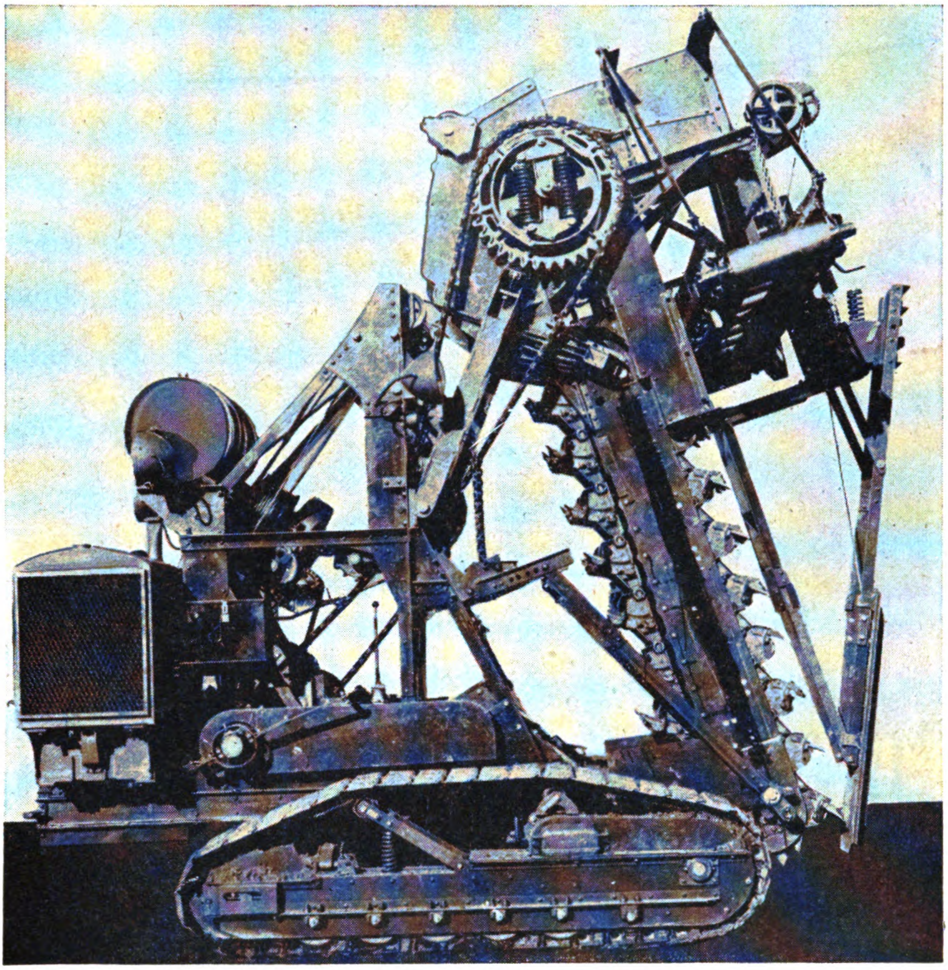


Figure 236. Ditching machine, ladder-type, crawler-mounted, gasoline-engine-driven, digging depth 8 feet, width 18 to 24 inches.

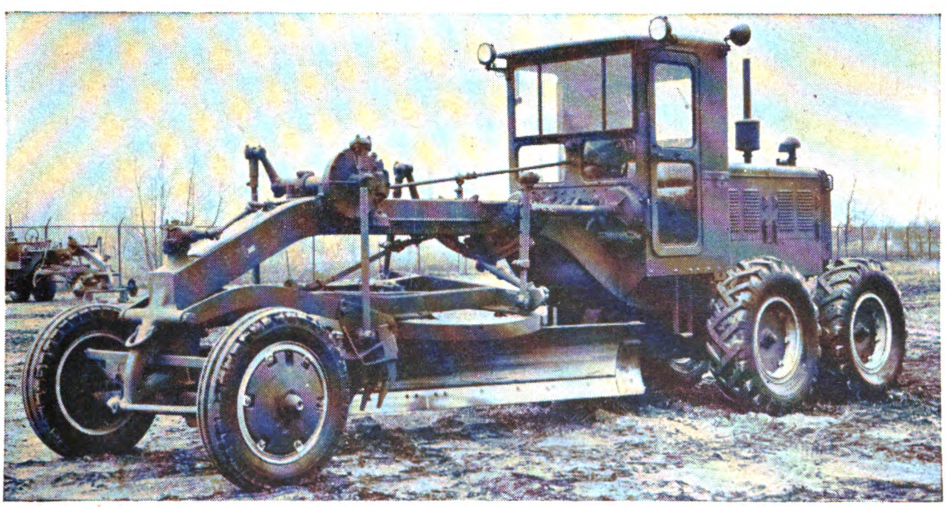


Figure 237. Grader, road, motorized, Diesel-engine-driven, 12-foot moldboard.

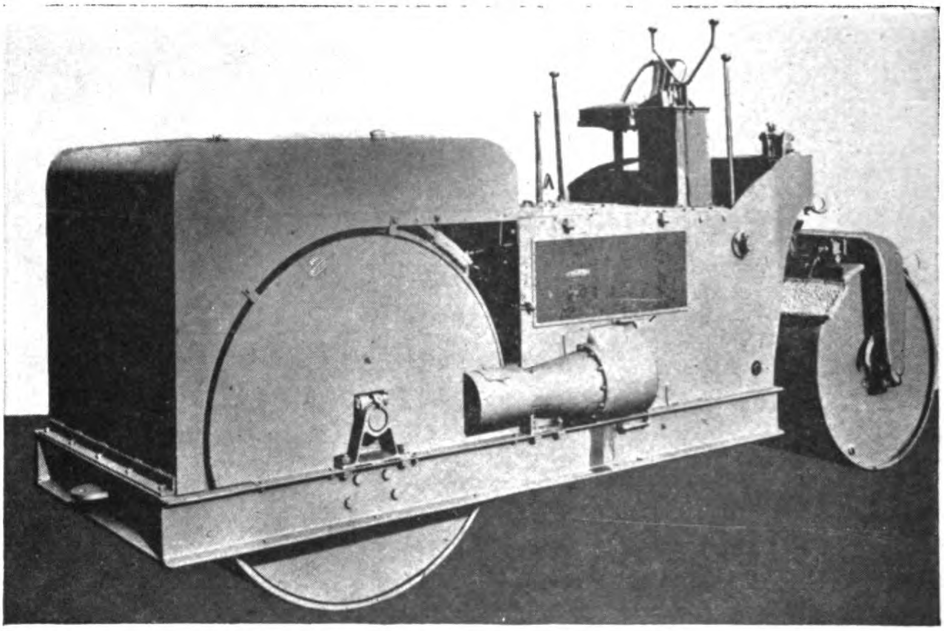


Figure 238. Roller, road, gasoline-engine-driven, tandem, two-axle, 5- to 8-ton.

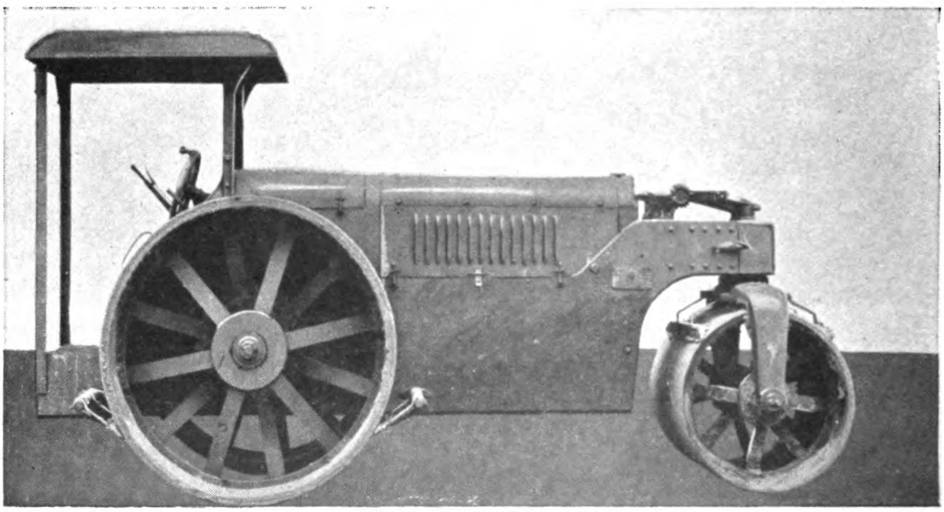


Figure 239. Roller, road, gasoline-engine-driven, three-wheel, 10-ton.

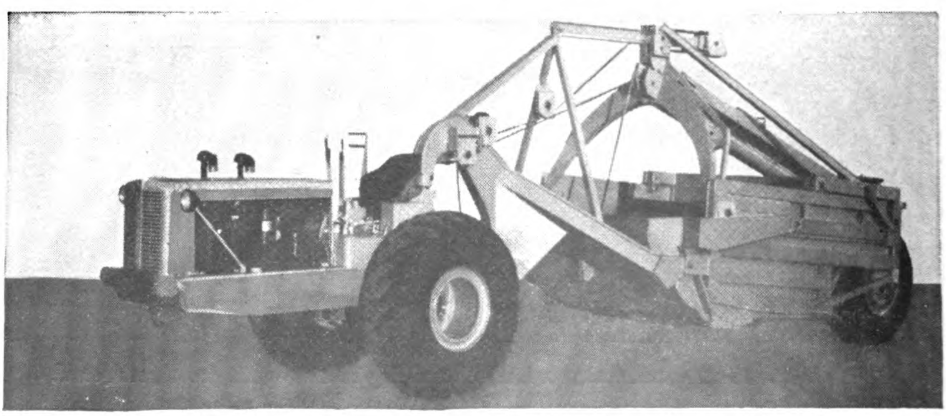


Figure 240. Scraper, road, motorized, cable-operated, 12-cubic-yard.

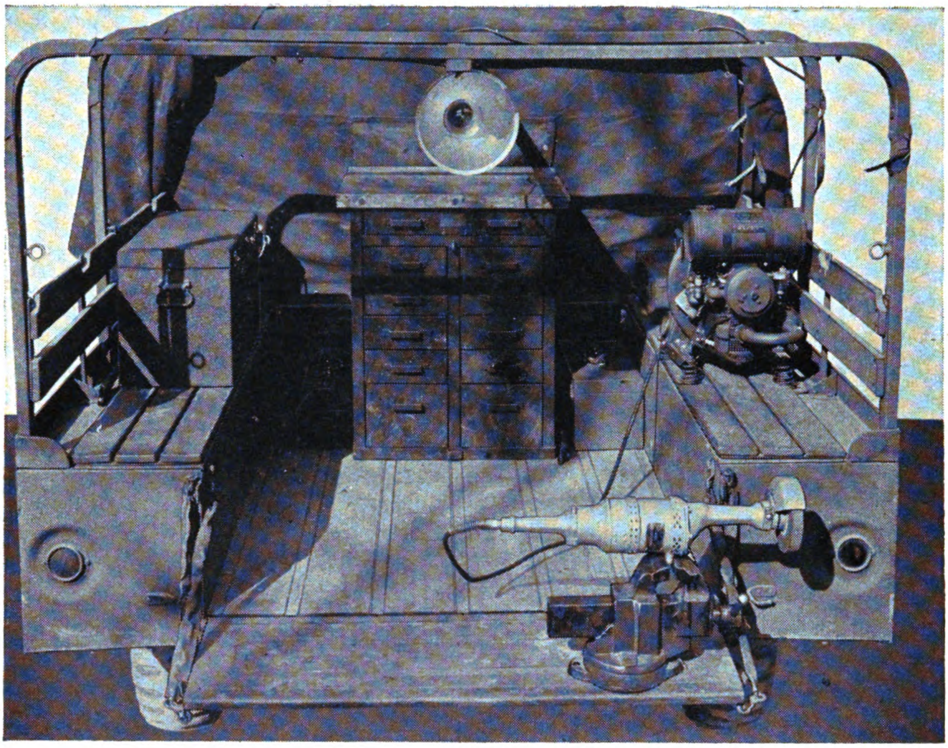


Figure 241. Shop equipment, third-echelon, motorized: set No. 2, emergency-repair.

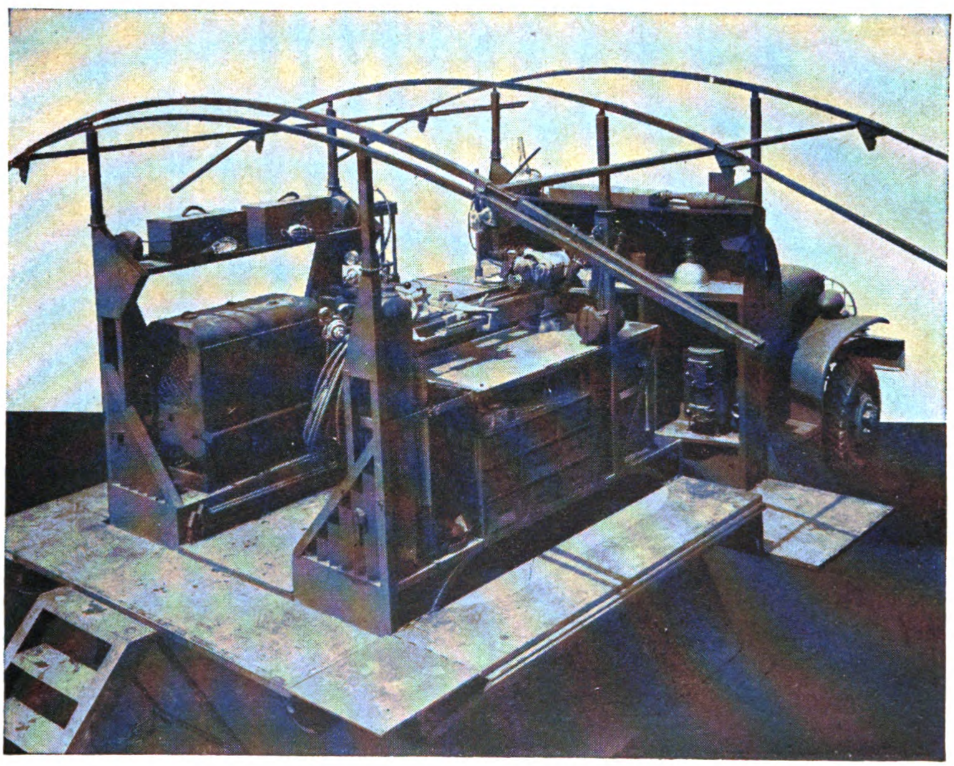


Figure 242. Shop equipment, third-echelon, motorized: set No. 3, general-purpose.

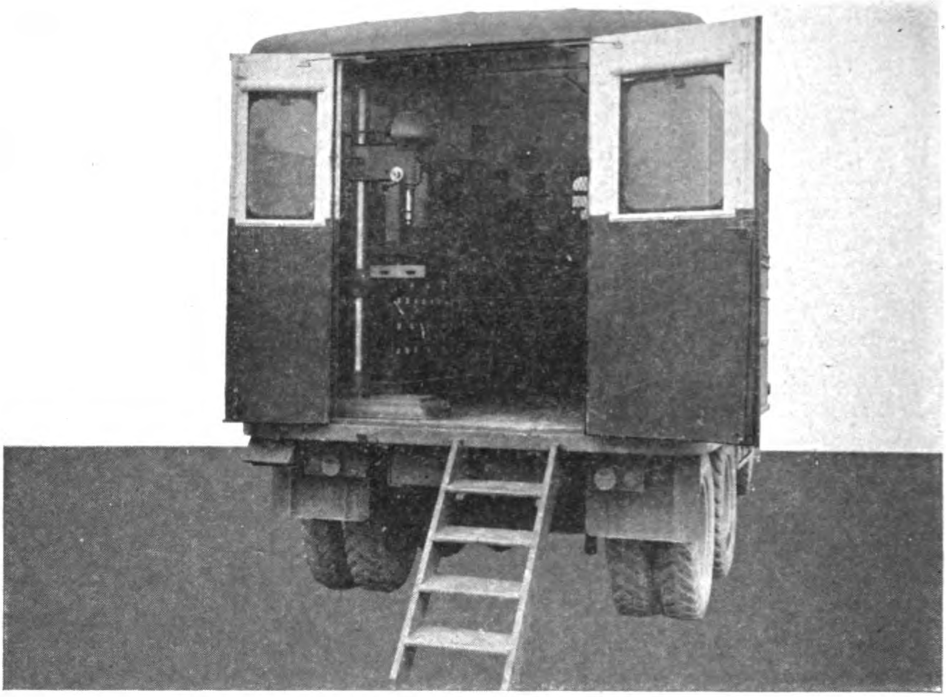


Figure 243. Shop equipment, third-echelon, motorized: set No. 4, machine-shop, heavy.

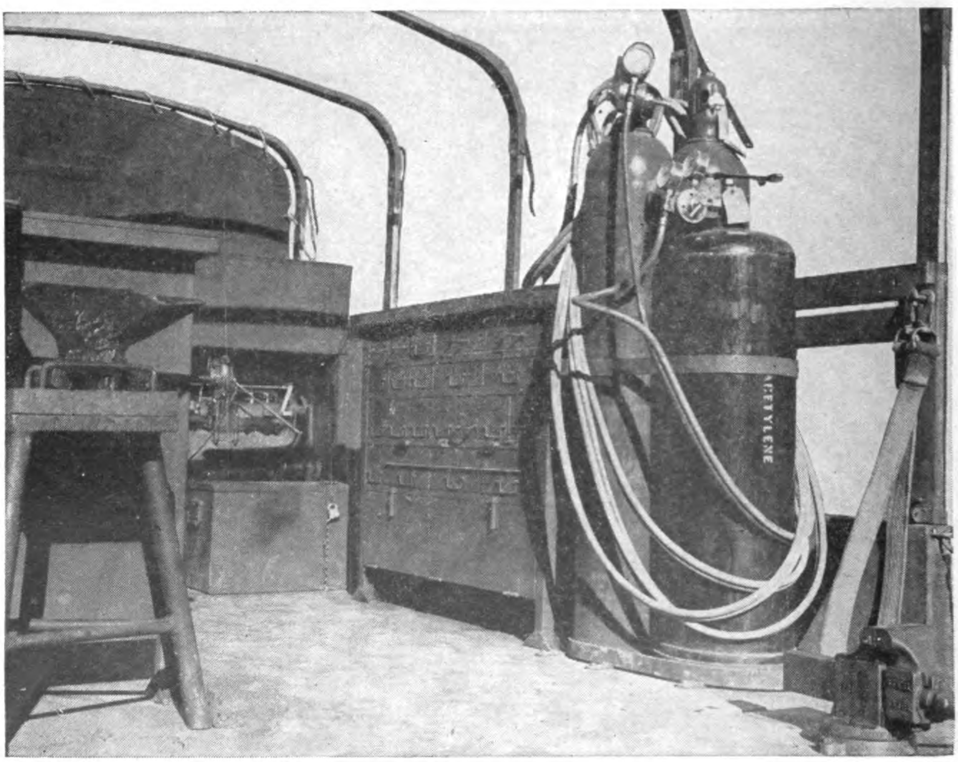


Figure 244. Shop equipment, third-echelon, motorized: set No. 9, welding.

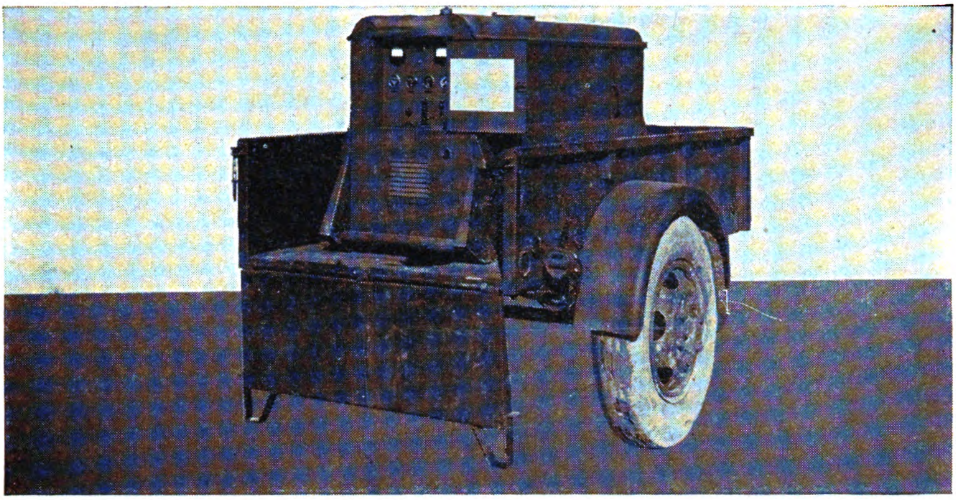


Figure 245. Shop equipment, third-echelon, motorized: power plant, 5-kw, trailer-mounted.

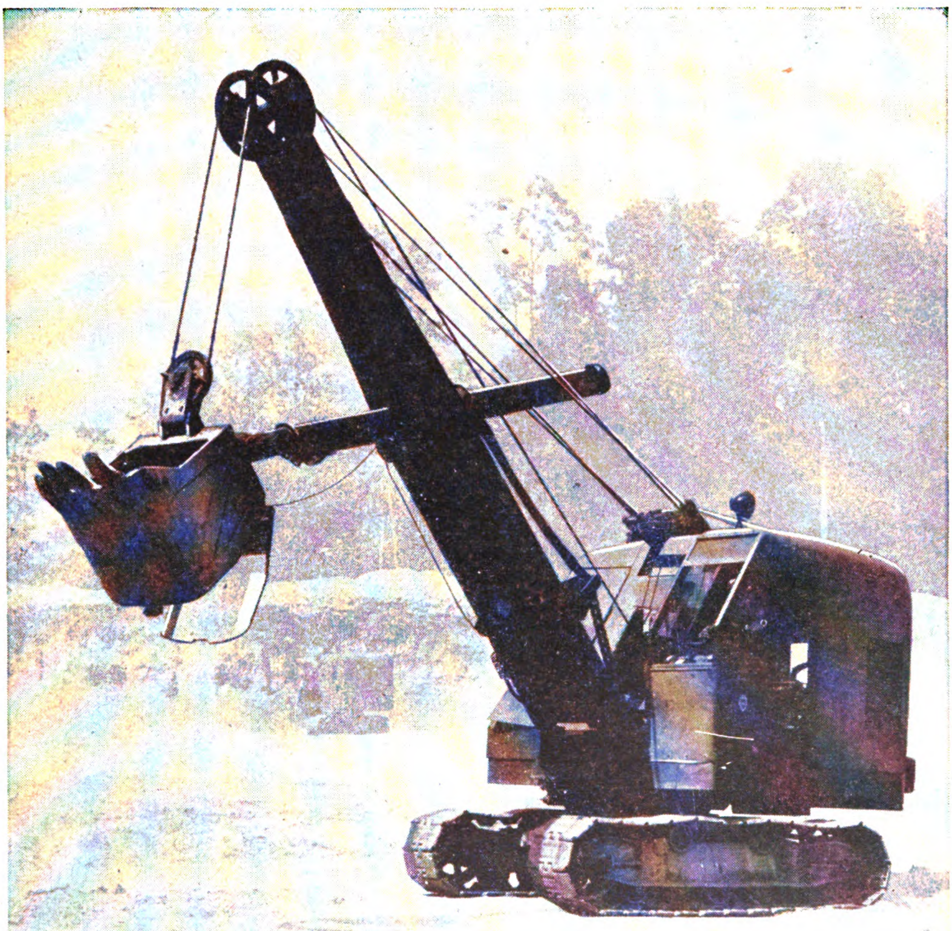


Figure 246. Shovel, crawler-mounted, gasoline-engine-driven, ¾-cubic yard, with attachments.

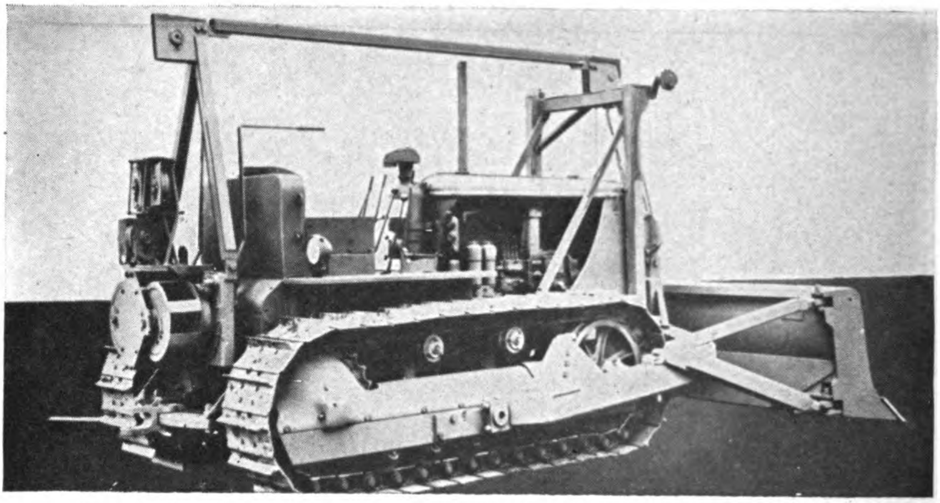


Figure 247. Tractor, crawler-type, Diesel-engine-driven, 70 to 90 DBHP with angledozer.

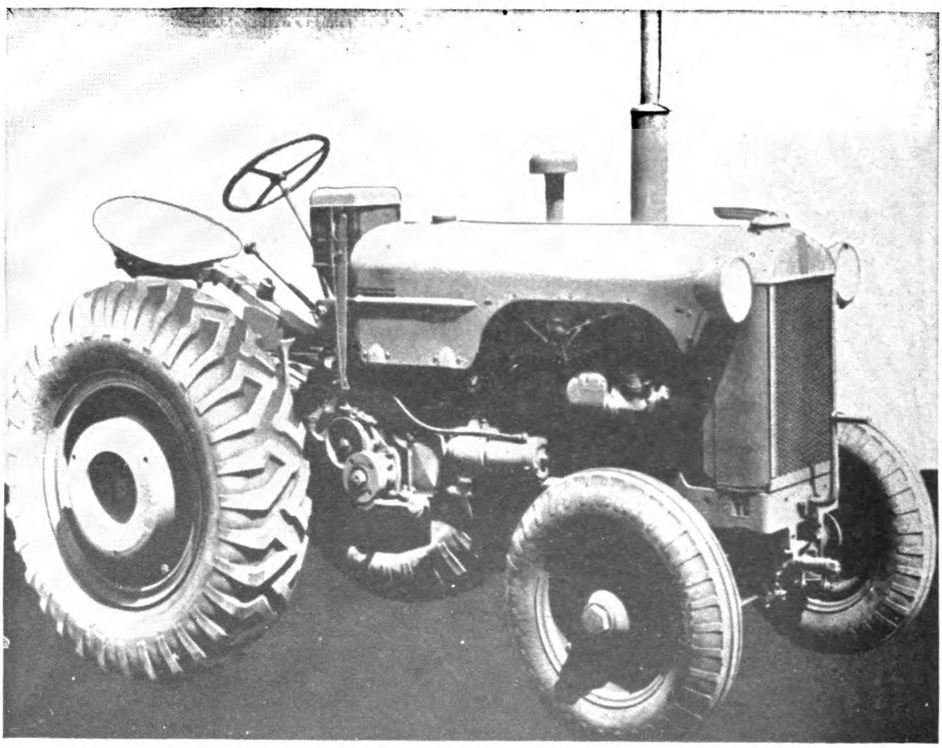


Figure 248. Tractor, wheeled, rubber-tired, gasoline-engine-driven, 30 DBHP.

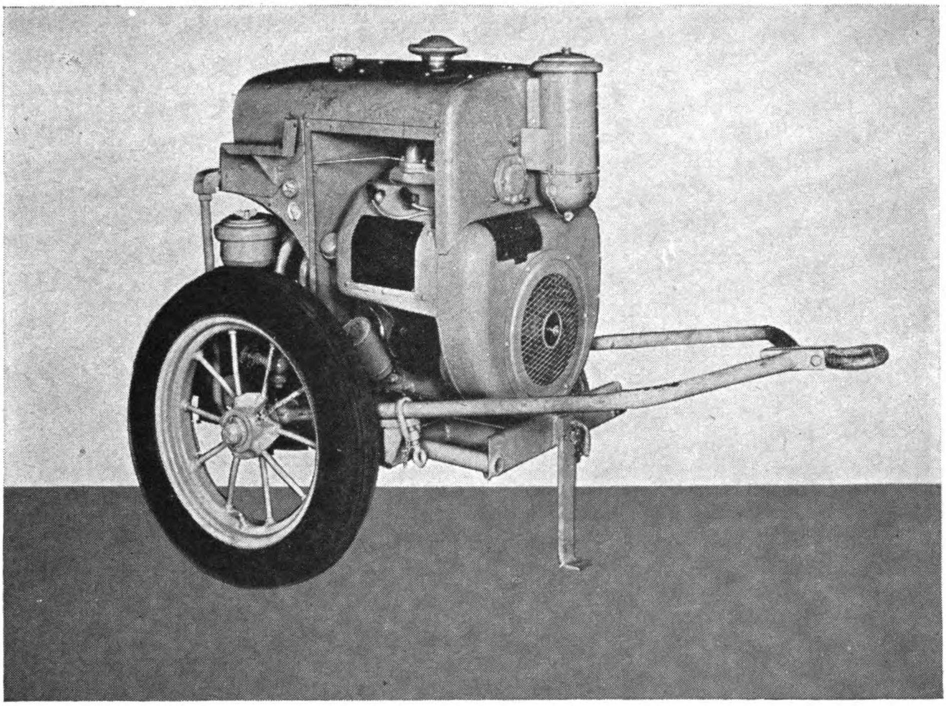


Figure 249. Compressor, air, trailer-mounted, pneumatic-tired, gasoline-engine-driven, 60-cfm.

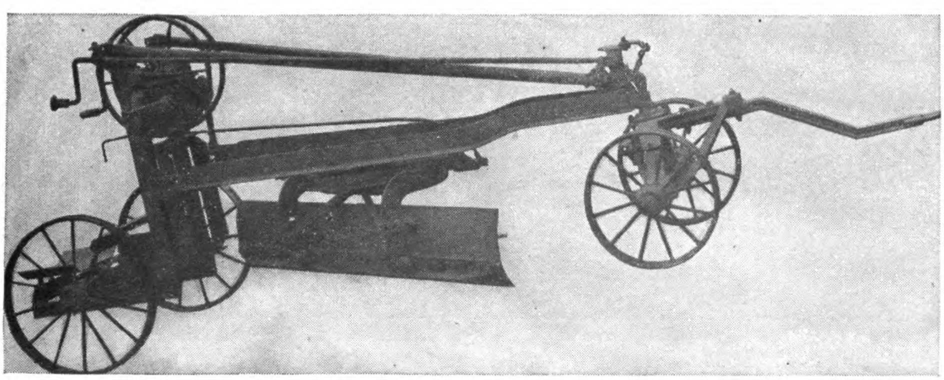


Figure 250. Grader, road, towed, leaning-wheel, hand-controlled, 6½-foot moldboard.

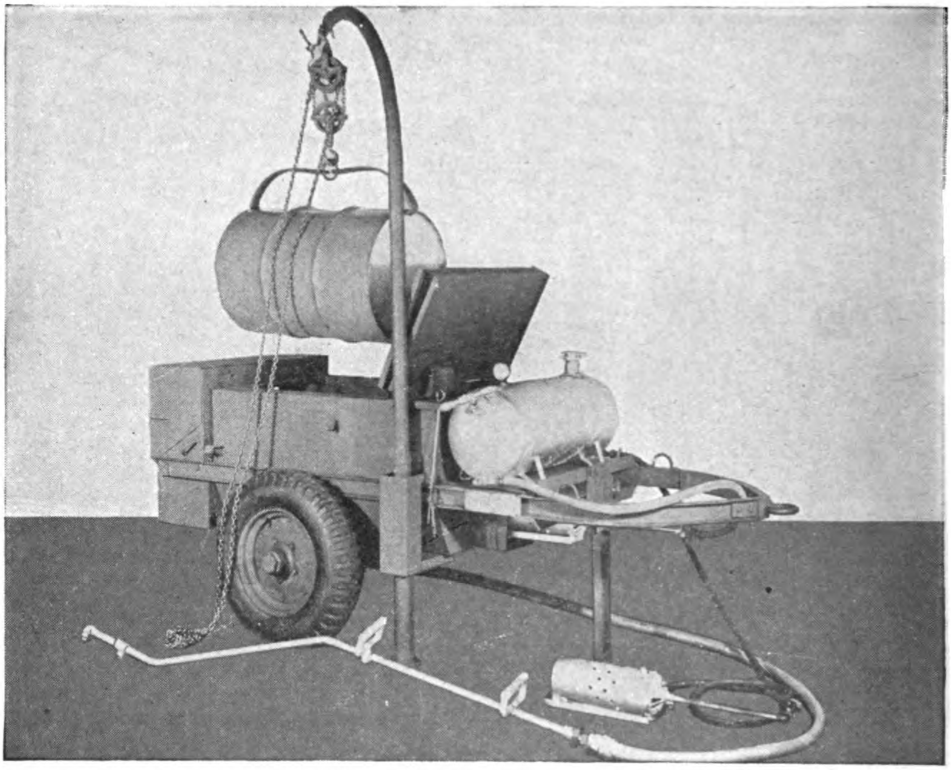


Figure 251. Kettle, asphalt-repair, trailer-mounted, with motor-driven hand spray, 110-gallon capacity.

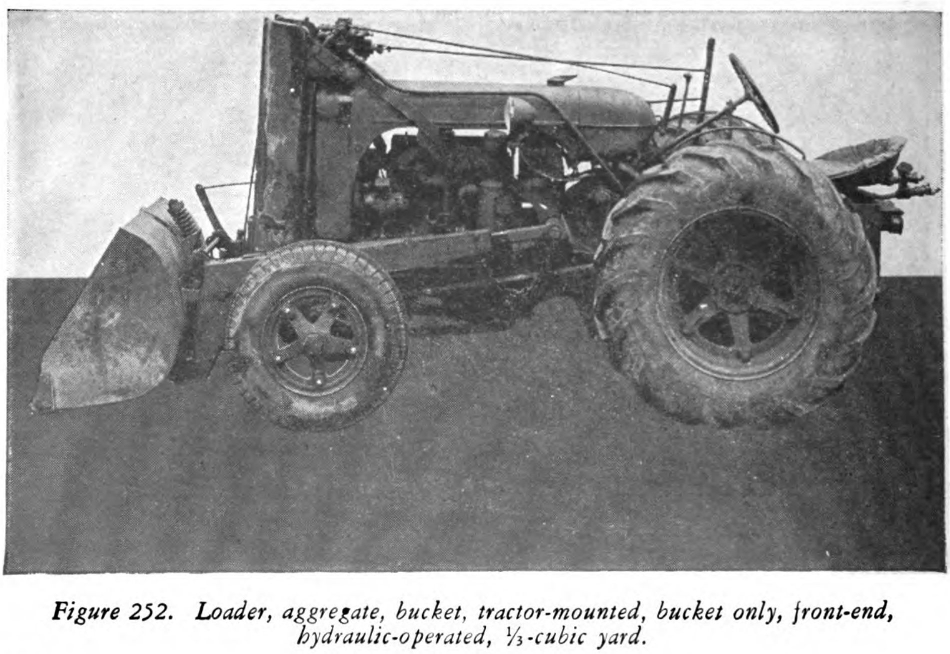


Figure 252. Loader, aggregate, bucket, tractor-mounted, bucket only, front-end, hydraulic-operated, ⅓-cubic yard.

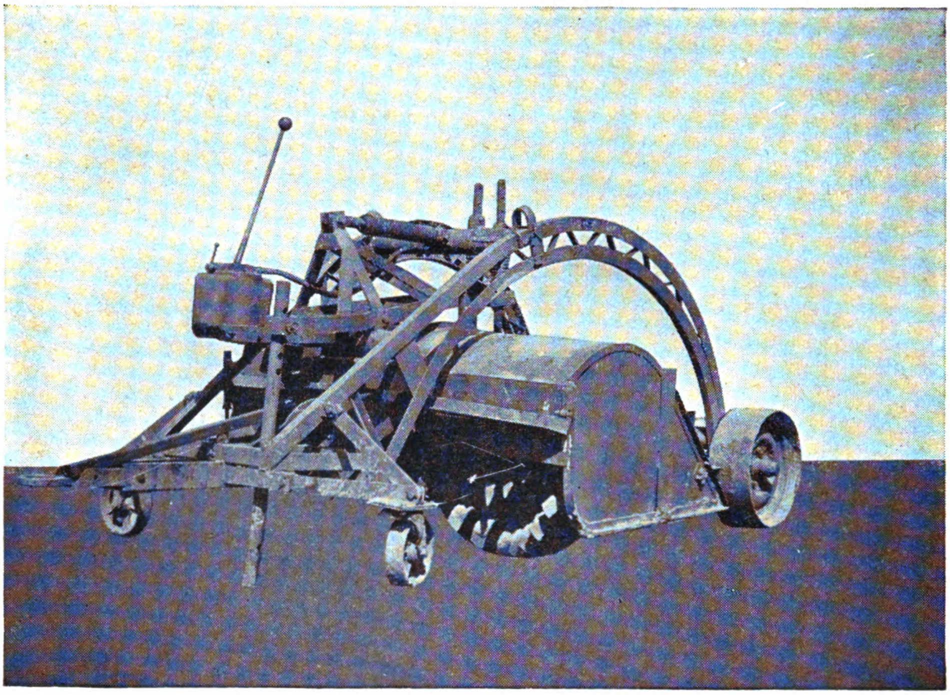


Figure 253. Mixer, rotary-tiller, soil-stabilization, power take-off, trailer-mounted.

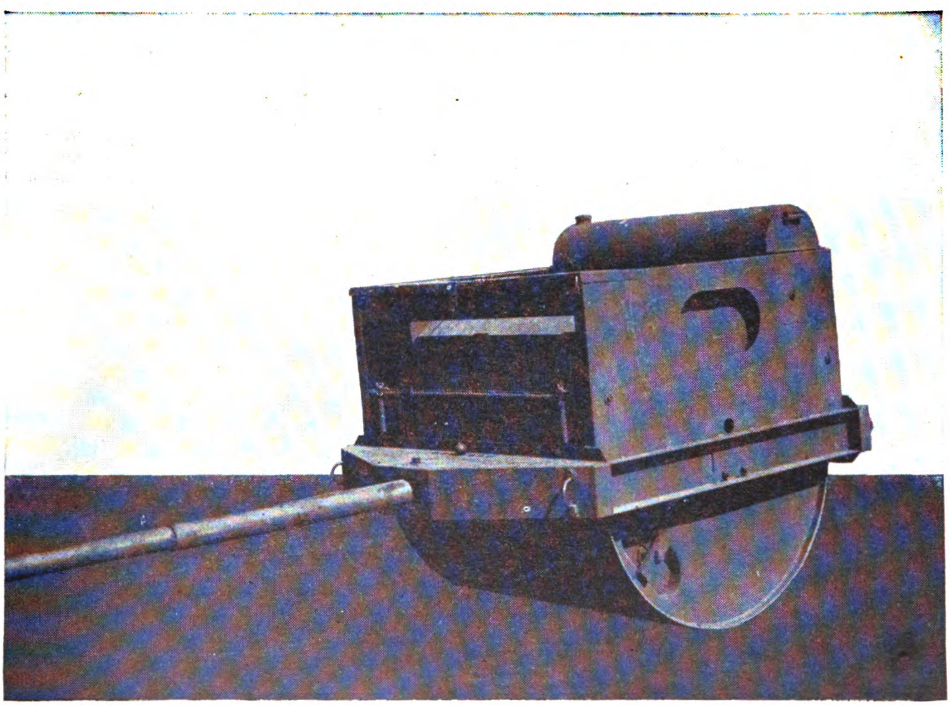


Figure 254. Roller, road, towed type, smooth-drum, 5-ton water load.

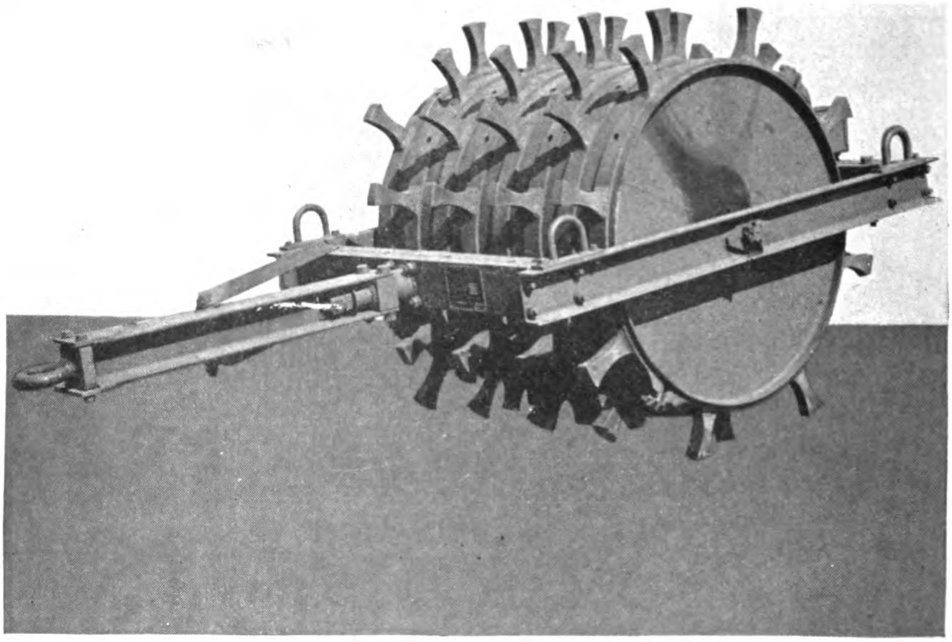


Figure 255. Roller, road, towed, sheepsfoot, single-drum, with removable teeth.

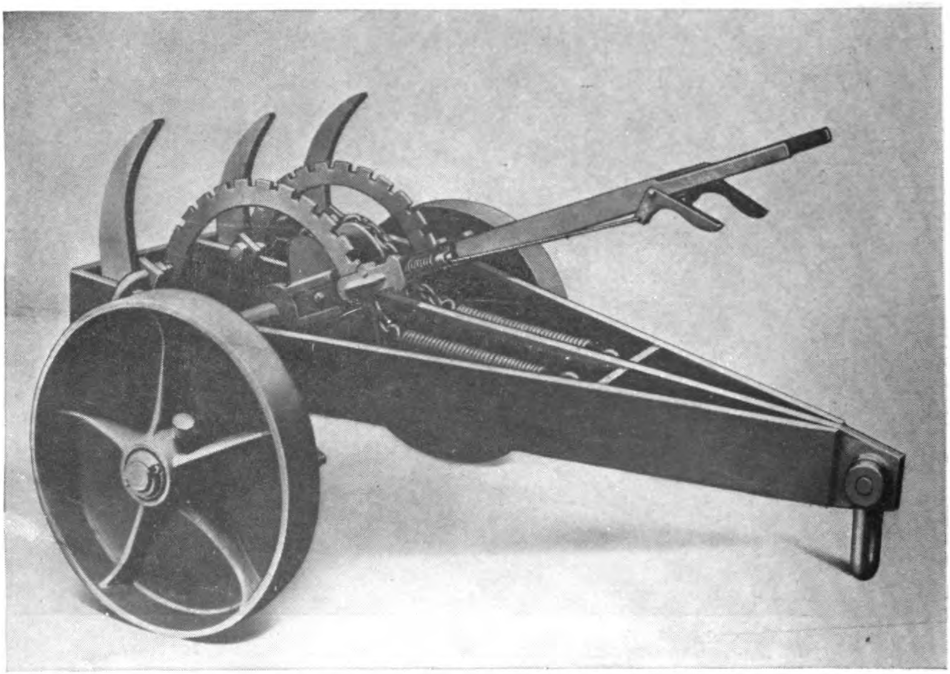


Figure 256. Rooter, road, lever-operated, three-tooth.

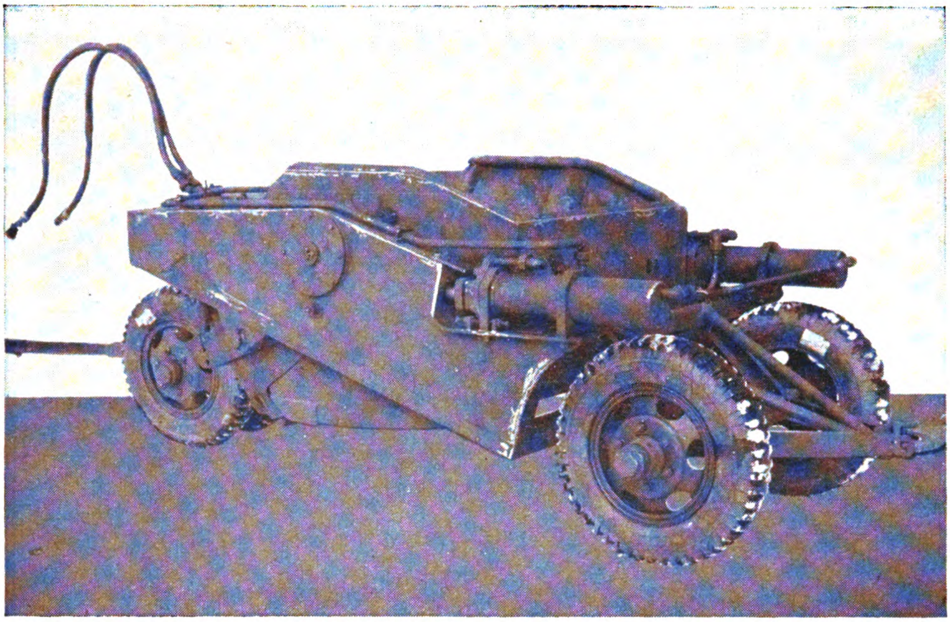


Figure 257. Scraper, road, towed type, hydraulically operated, 1½-cubic yard.

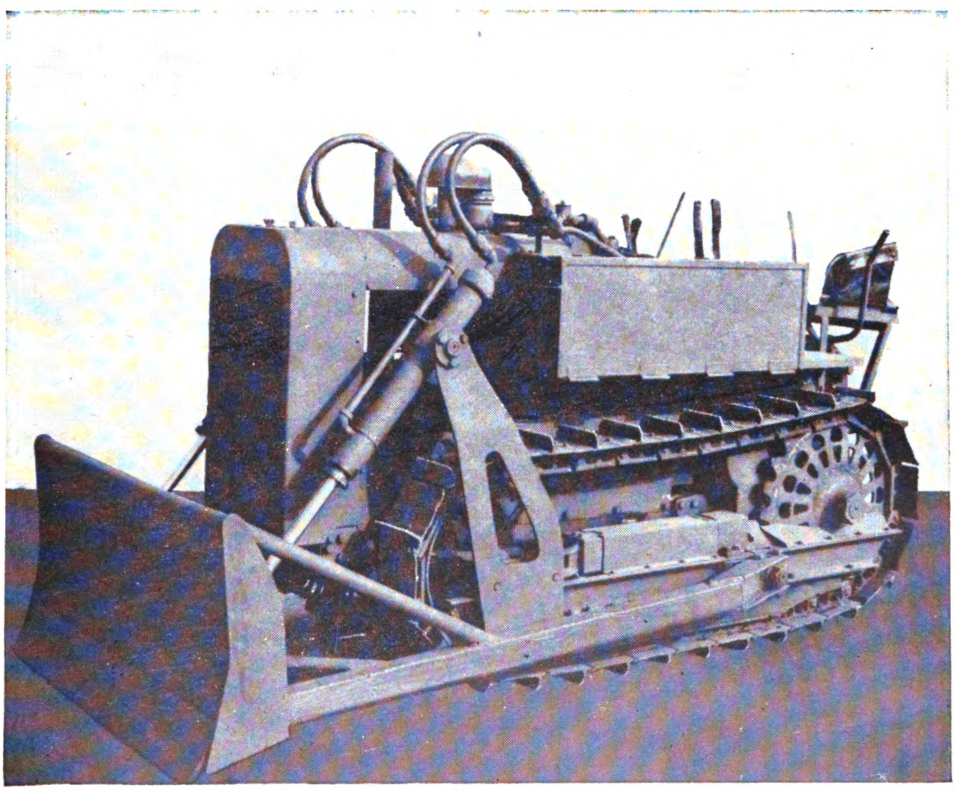


Figure 258. Tractor, crawler-type, gasoline-engine-driven, with hydraulic controls, bulldozer, and winch, 20-DBHP.

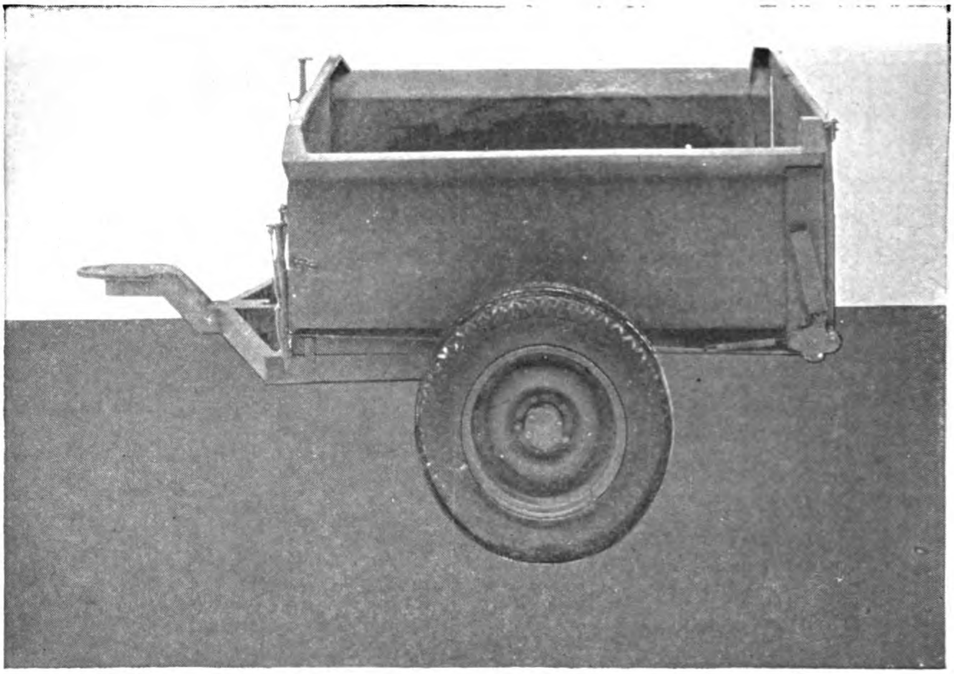


Figure 259. Trailer, dump, two-wheel, ½-ton.

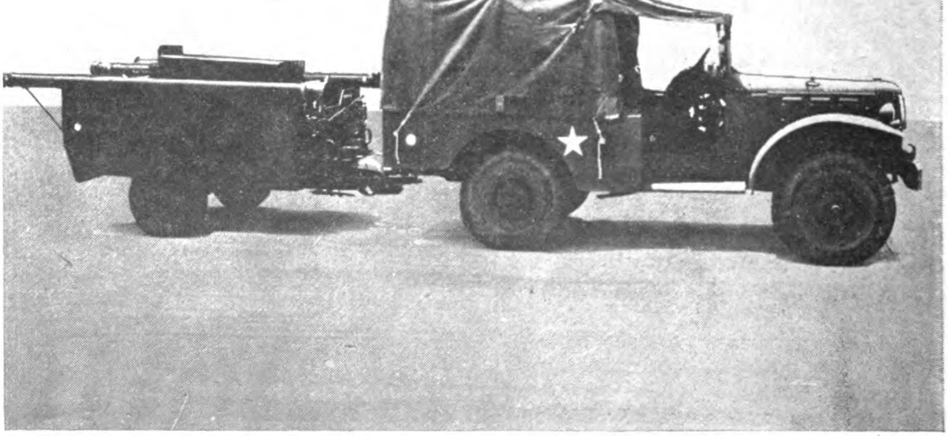


Figure 260. Trailer, fire, pumper, two-wheel, 500-g.p.m. class 1,000, complete with equipment.

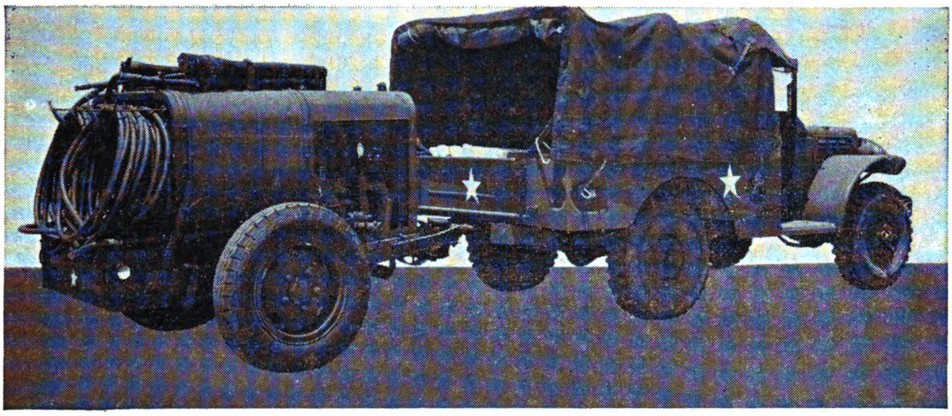


Figure 261. Trailer, fire, crash, two-wheel, high-pressure, class 1,010, complete with equipment.

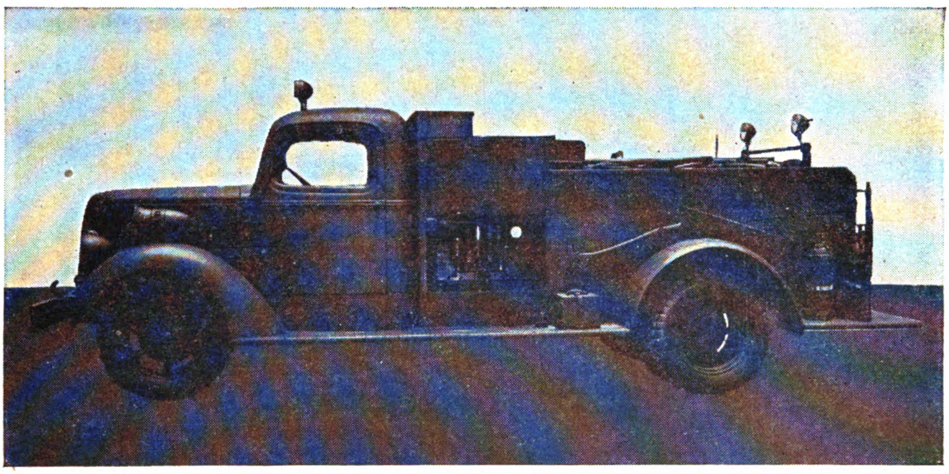


Figure 262. Truck, powered, fire, crash, class 125, complete with equipment.

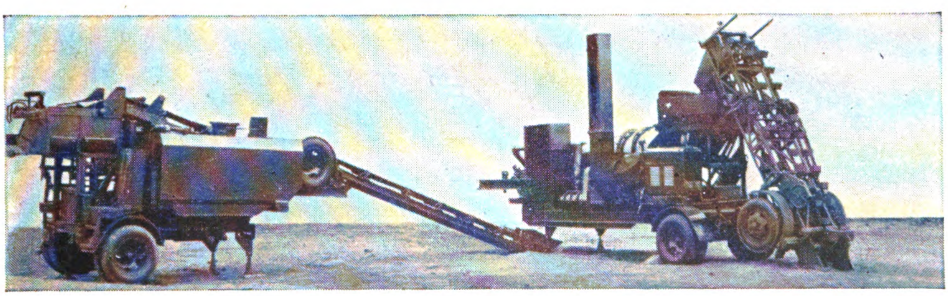
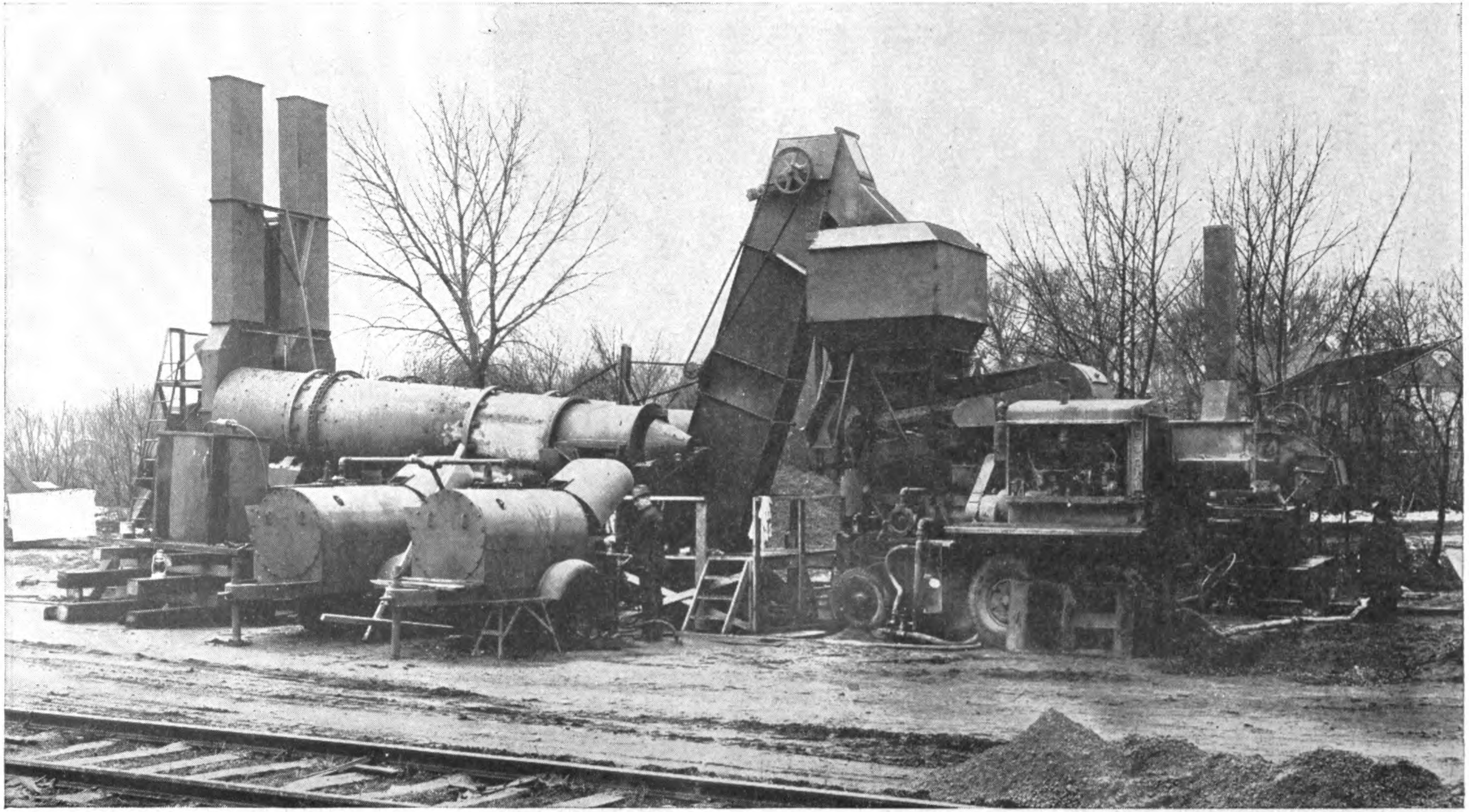
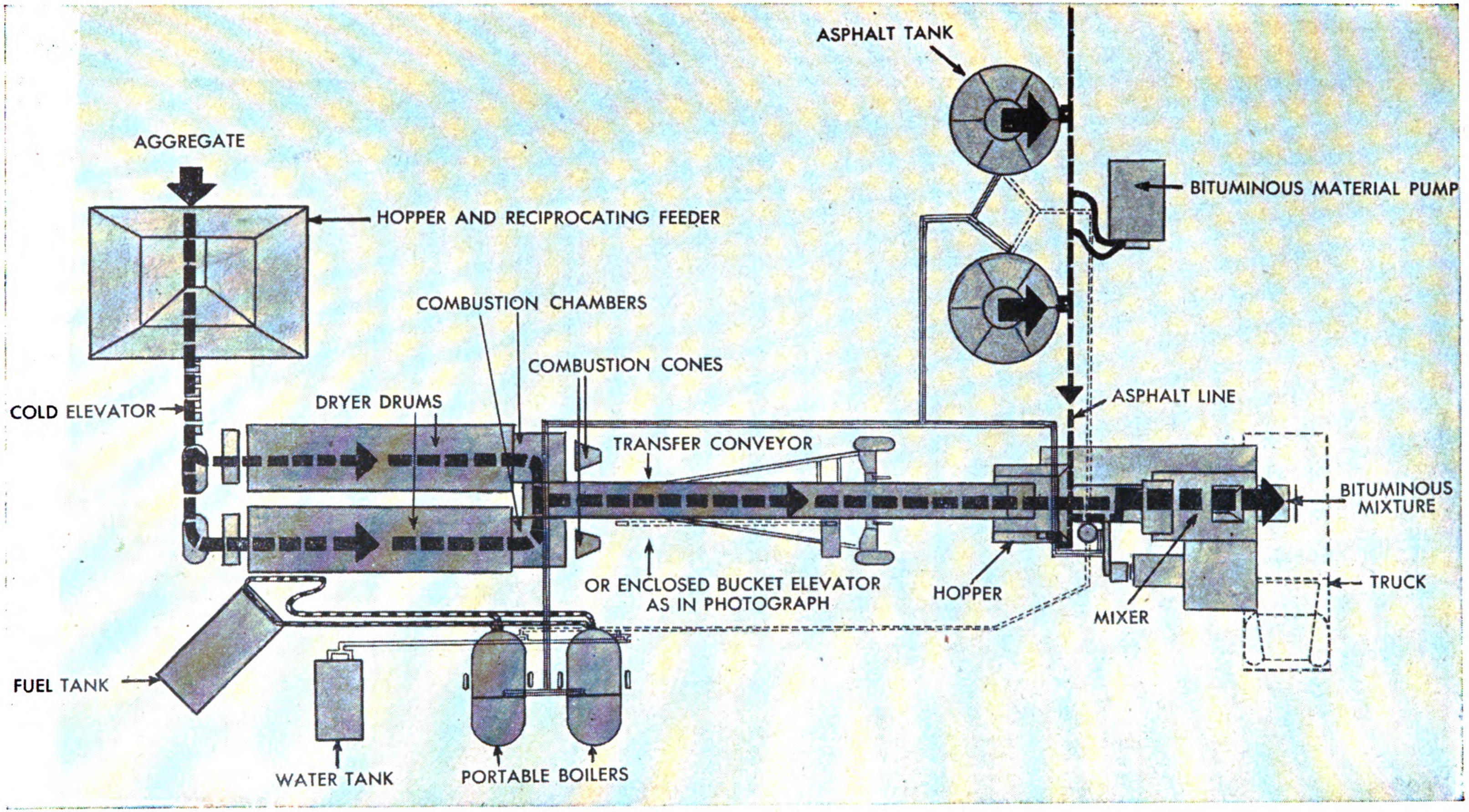


Figure 263. Asphalt and soil-aggregate mixing plant, gasoline-engine-driven, 25-ton per hour.



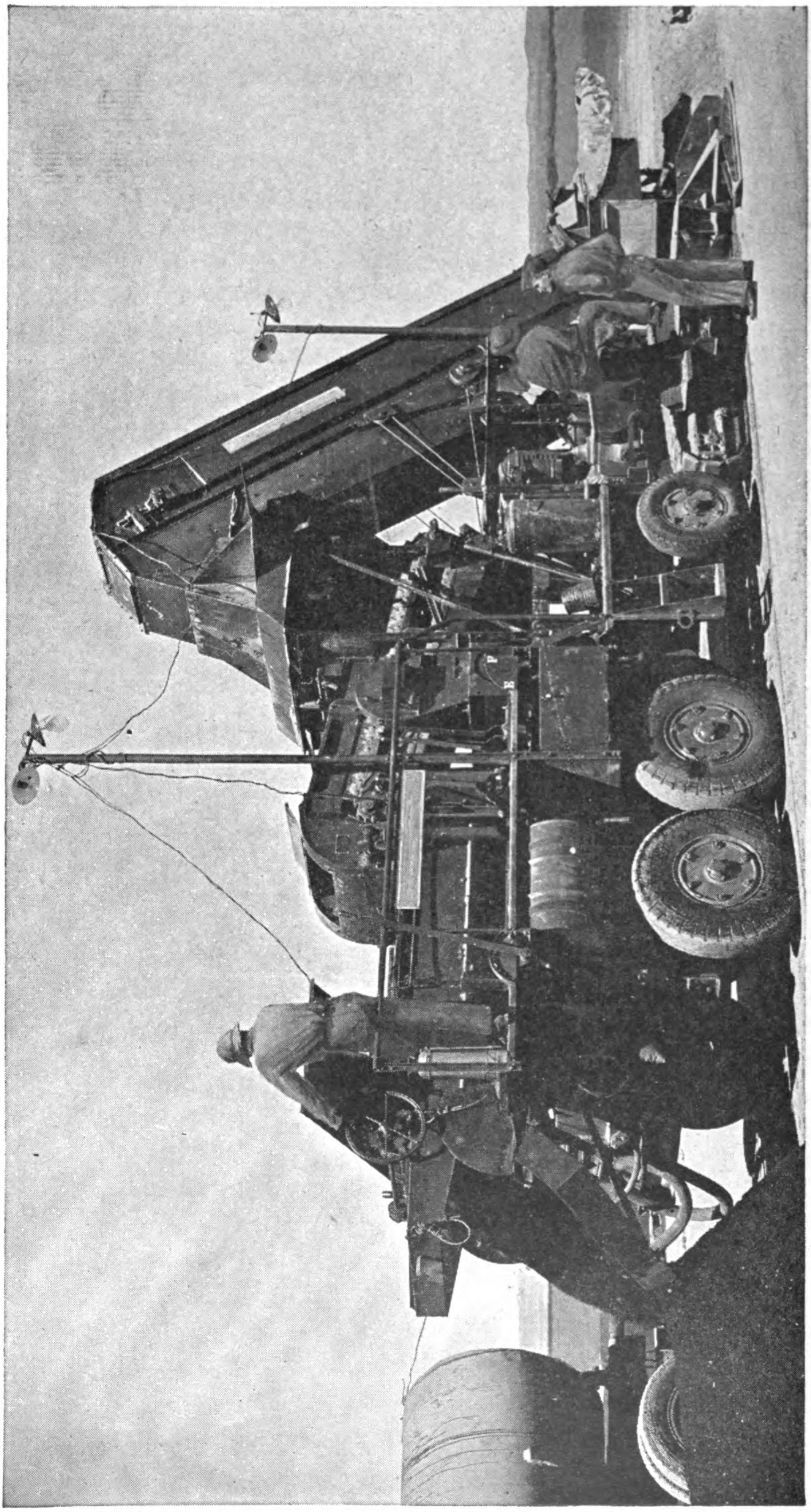
① Plant set-up.

Figure 264. Asphalt plant, 10-unit, 80 to 150 tons per hour.



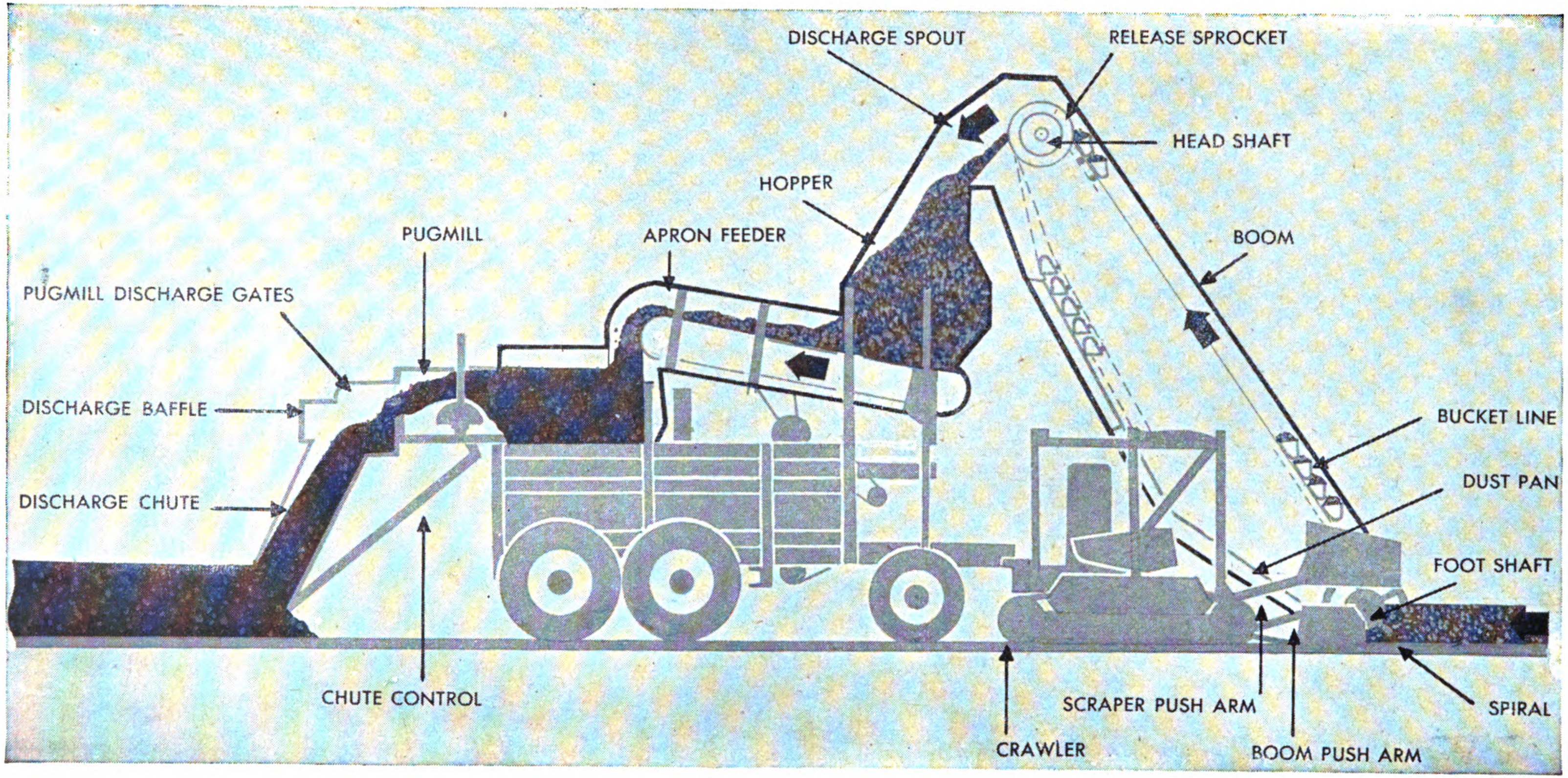
② *Flow diagram.*

Figure 264. Continued.



① *Plant set-up.*

Figure 265. Traveling asphalt plant consisting of bucket loader and mixer from set shown in figure 264.



② *Flow diagram.*
Figure 265. Continued.

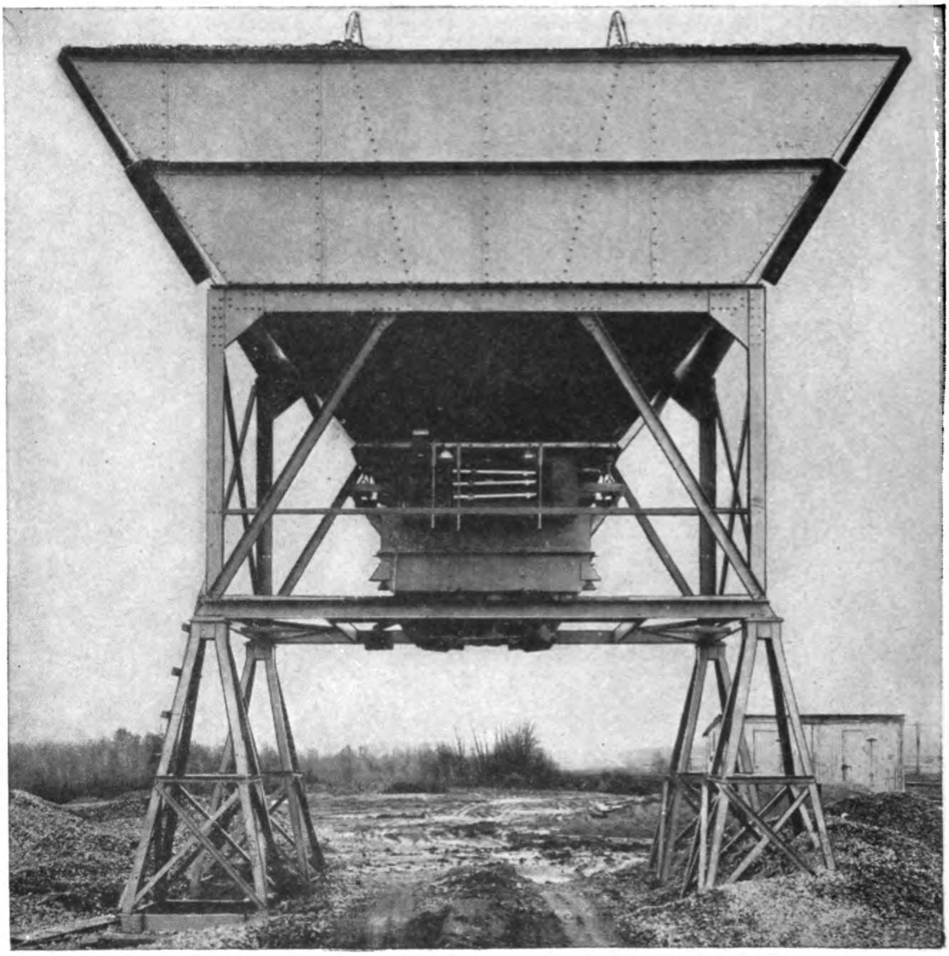


Figure 266. Batching plant, aggregate, three-compartment, 105-ton capacity.

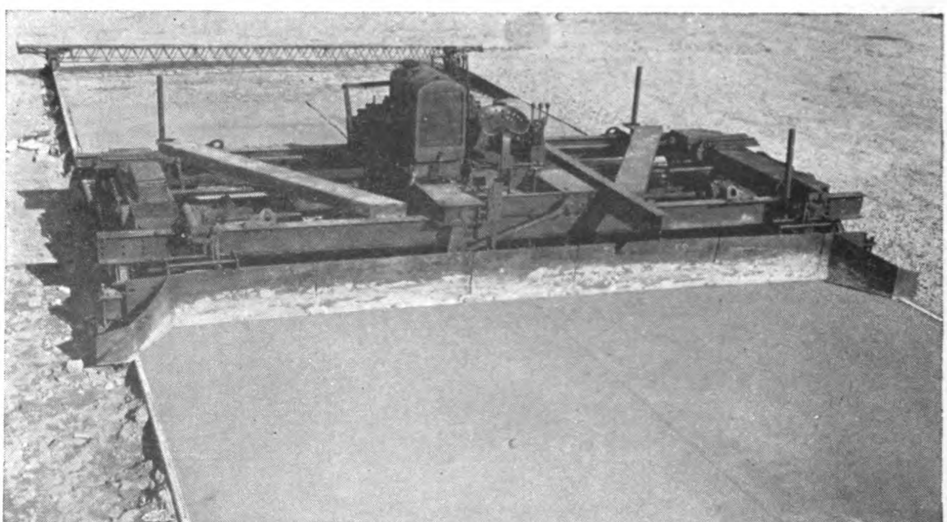


Figure 267. Finisher, concrete, form-riding, 20-foot.

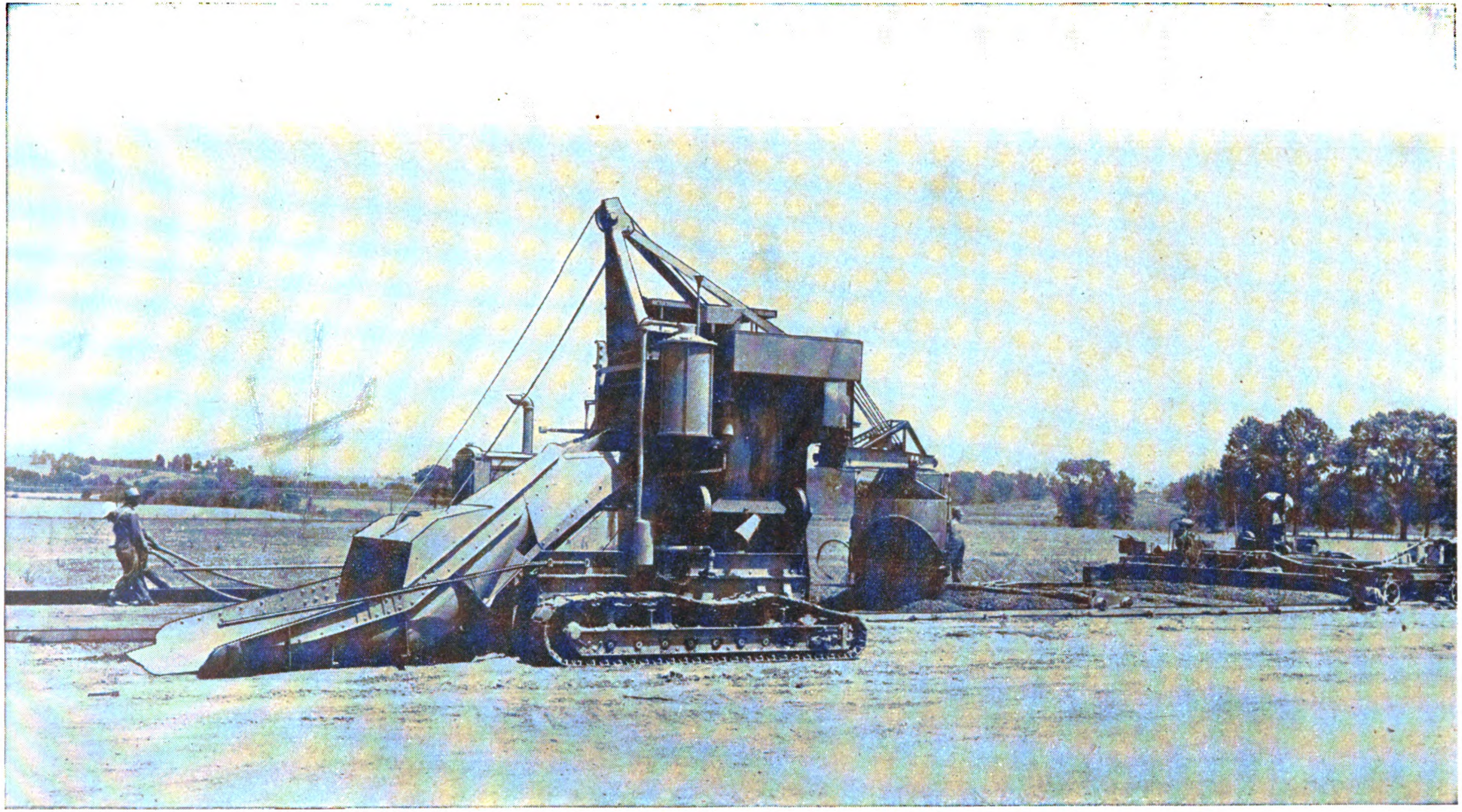


Figure 268. Paver, concrete, crawler-mounted, 34-cubic foot.

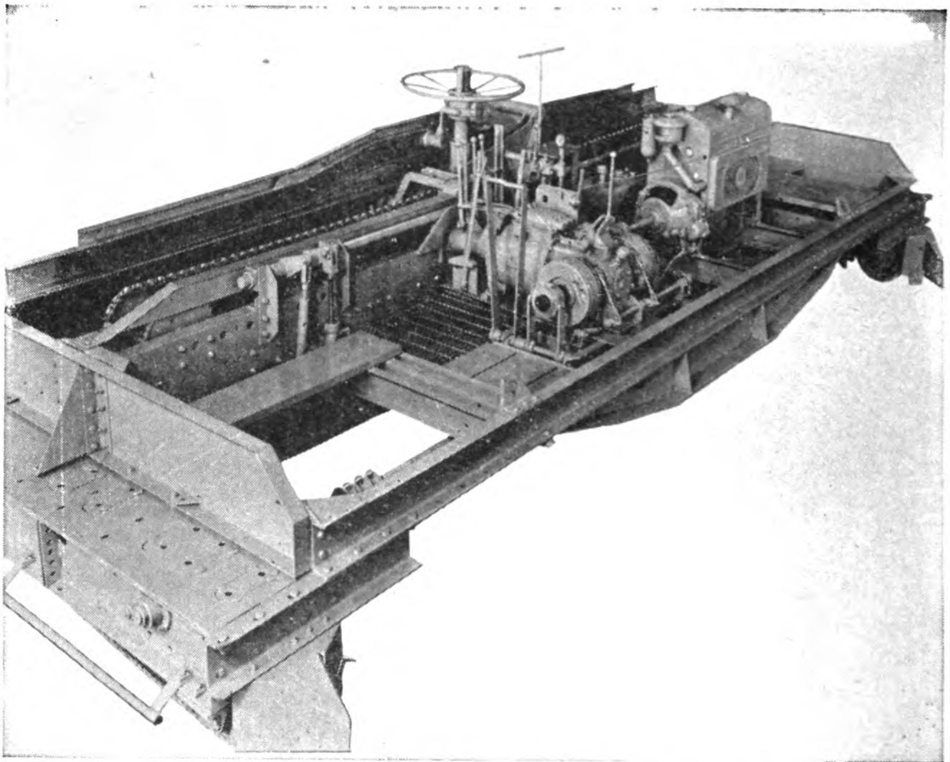


Figure 269. Spreader, concrete, gasoline-engine-driven, 20-foot width.

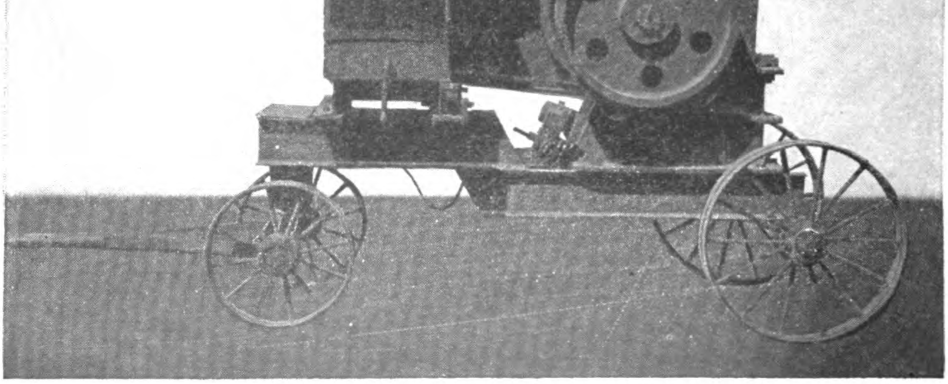


Figure 270. Crusher, rock, jaw type, four-wheel-trailer-mounted, 7 cubic yards per hour, gasoline-engine-driven.

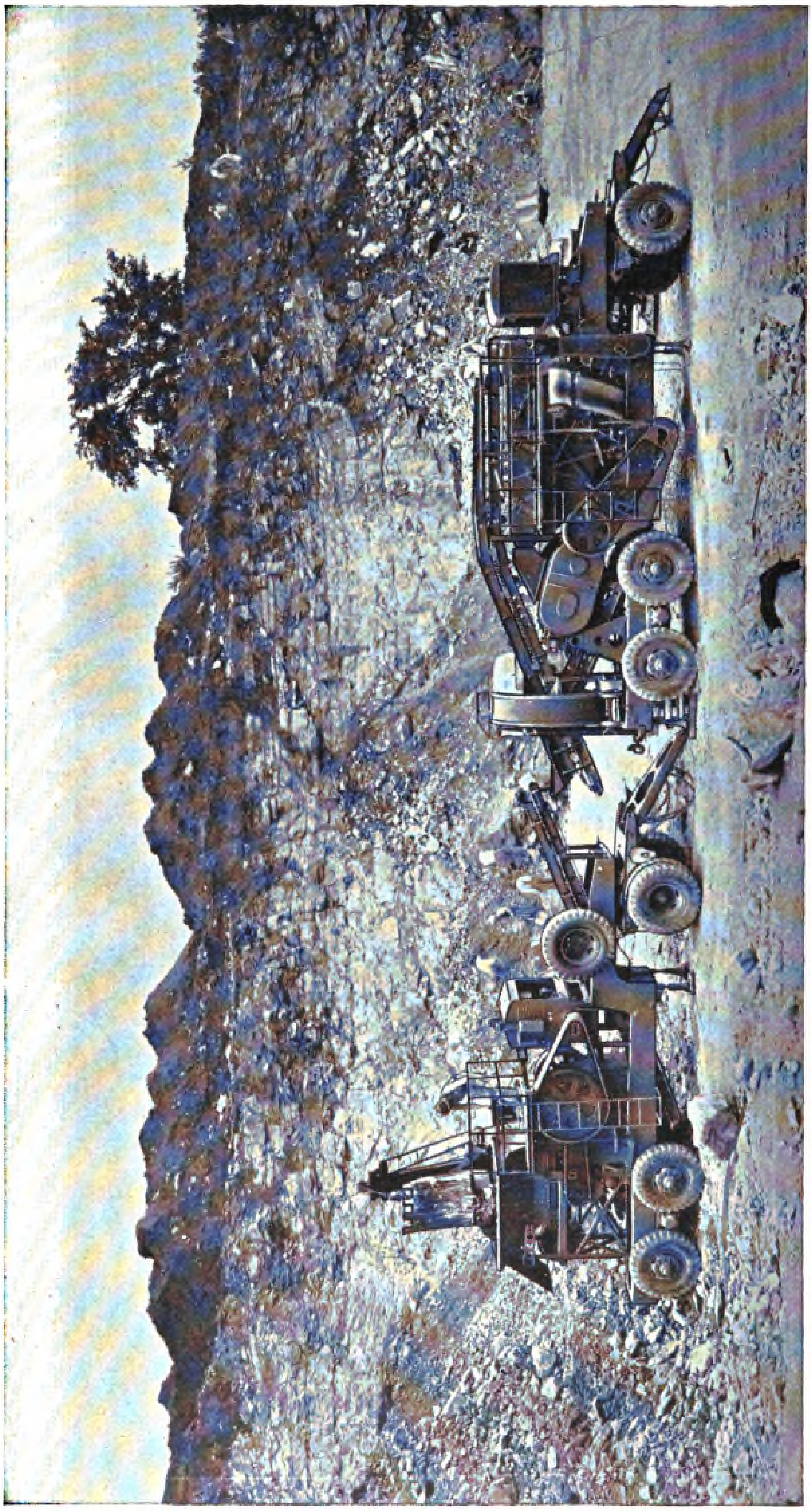
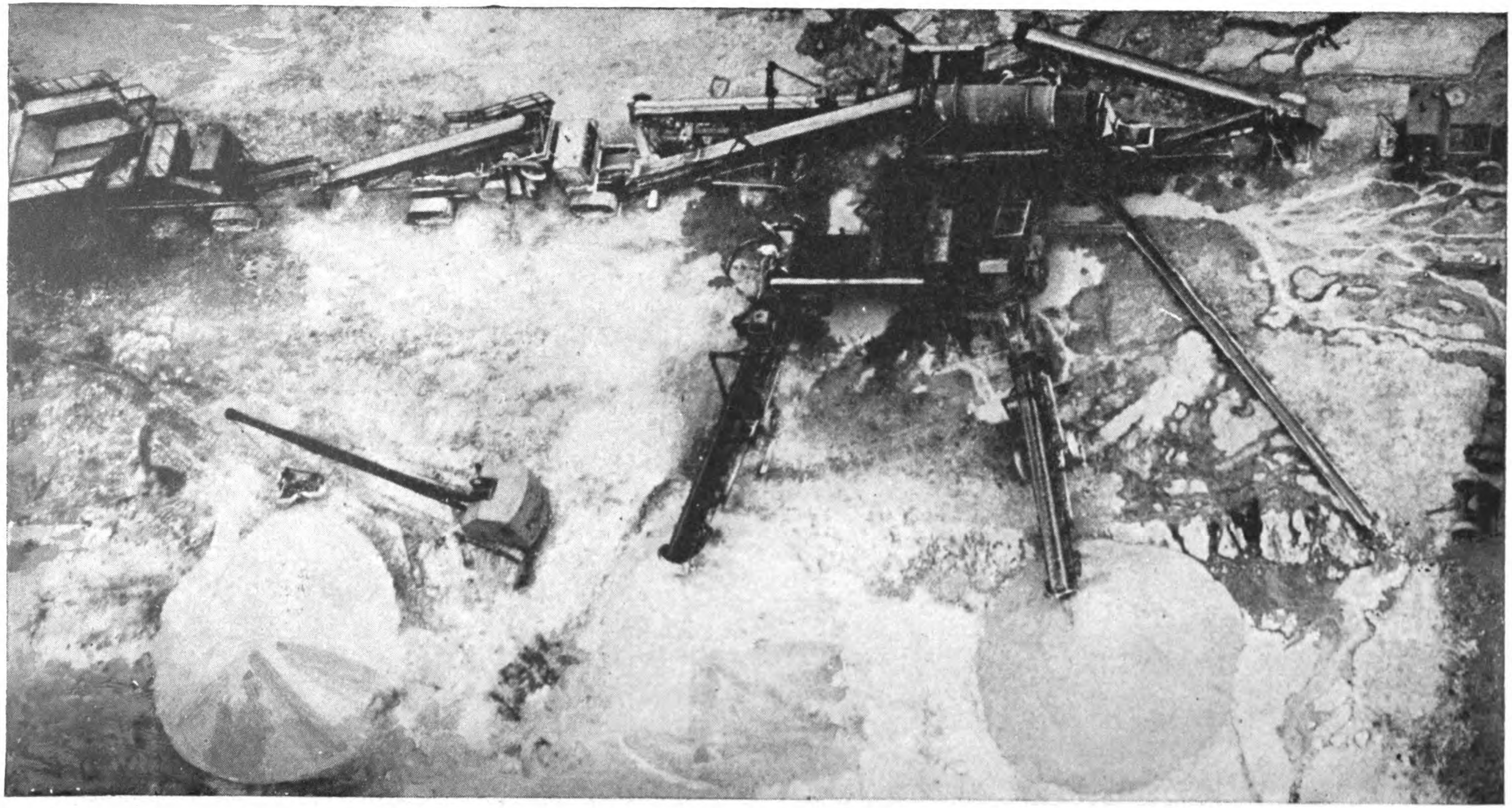
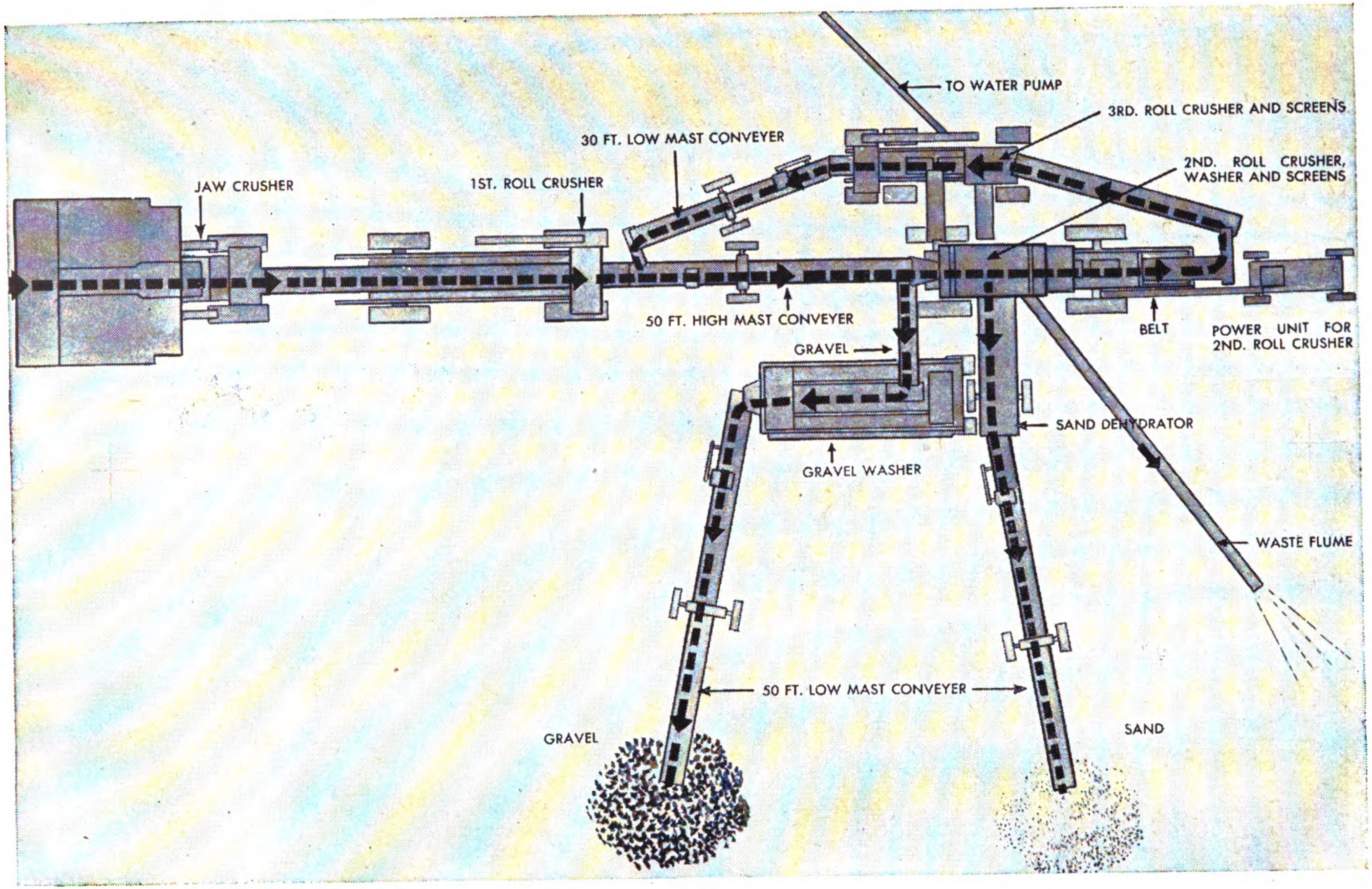


Figure 271. *Crushing and screening plant, gravel and rock, two-unit, gasoline-engine-driven, semitrailer-mounted, with dollies, 25 tons per hour.*



① *Plant set-up.*

Figure 272. Crushing, screening, and washing plant, rock, crawler-mounted, 150 tons per hour, gasoline-engine-driven, nine-unit.



② *Flow diagram.*

Figure 272. Continued.

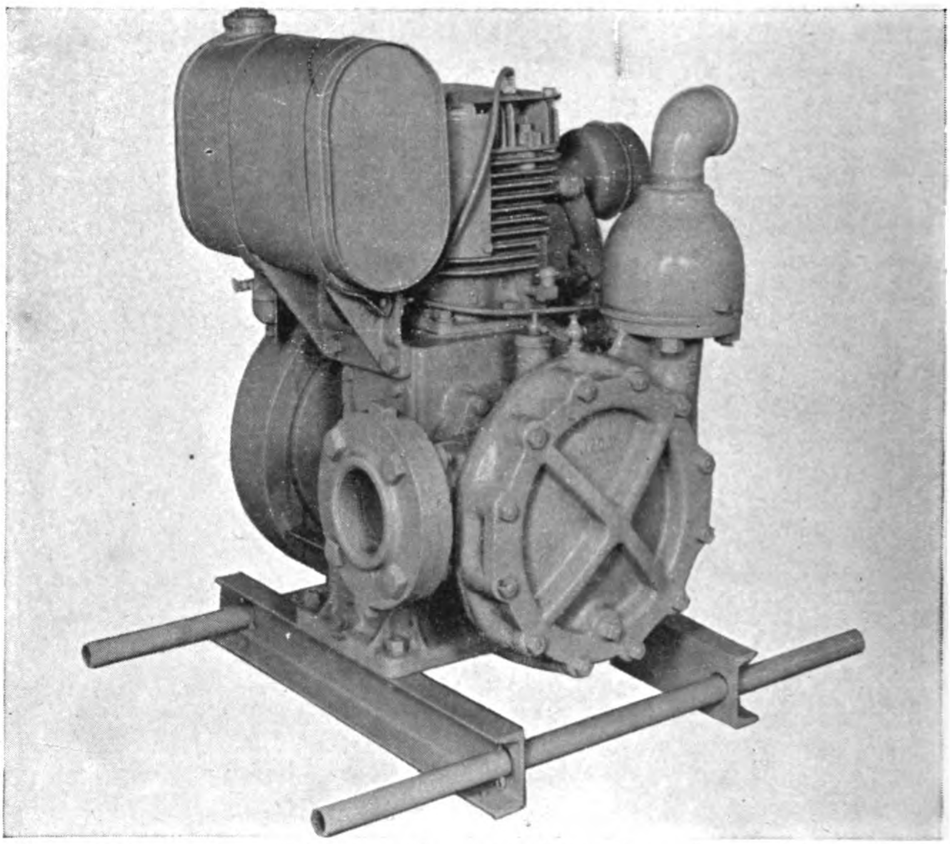


Figure 273. Pump, centrifugal, gasoline-engine-driven, base-mounted, 2-inch discharge, 60 gallons per minute, 125-foot head.

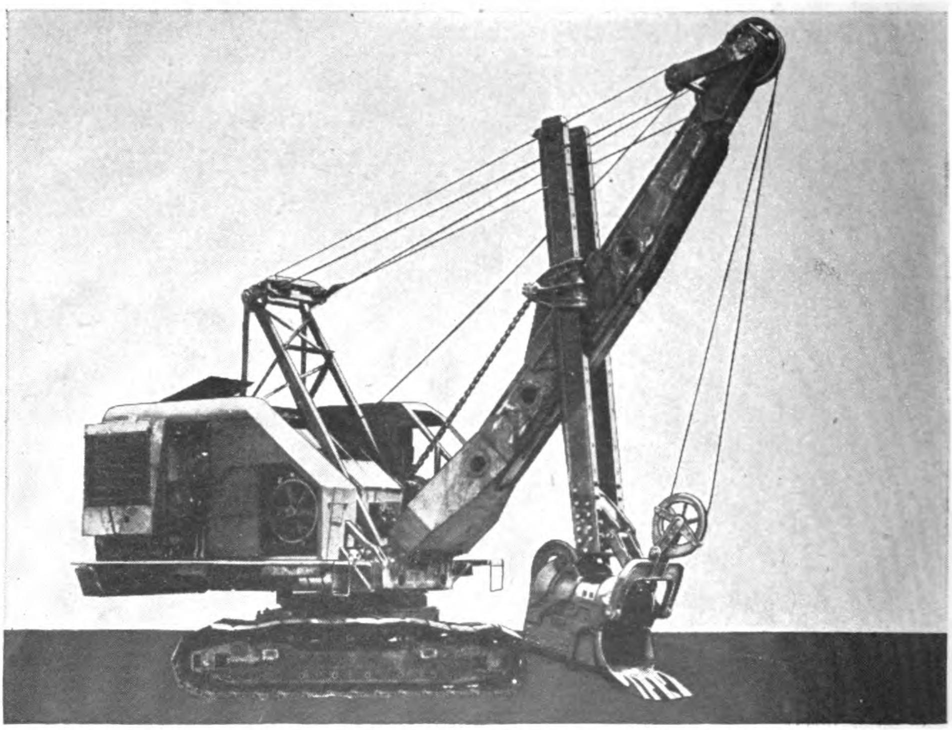


Figure 274. Shovel, crawler-mounted, Diesel-engine-driven, 2-cubic-yard, with attachments.

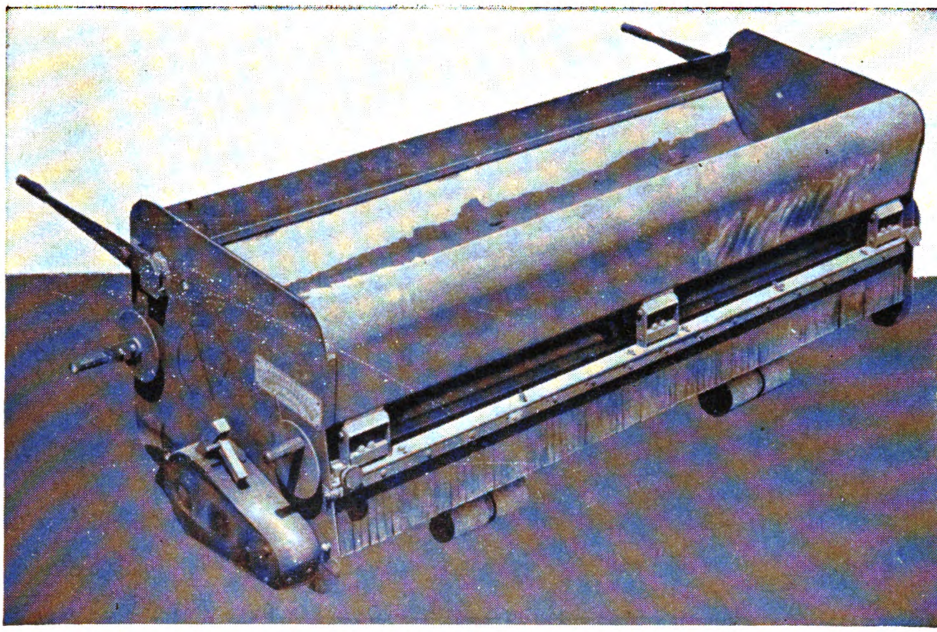


Figure 275. Spreader, aggregate, towed, traction-powered, 8 feet wide.

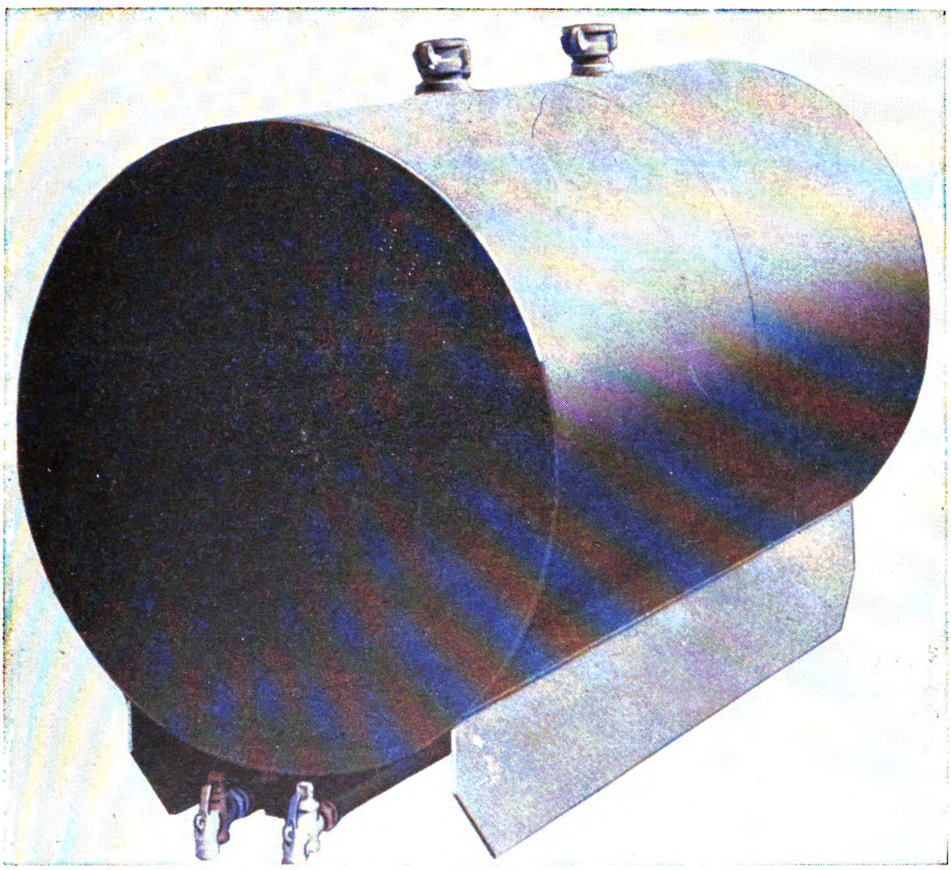


Figure 276. Tank, water-supply, skid-mounted, 750-gallon, two-compartment.

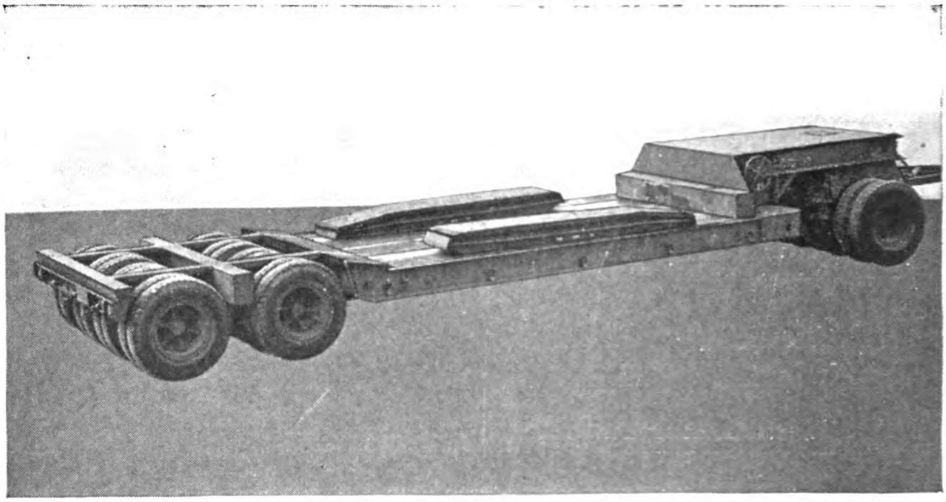


Figure 277. Trailer, full, low-bed, 60-ton.

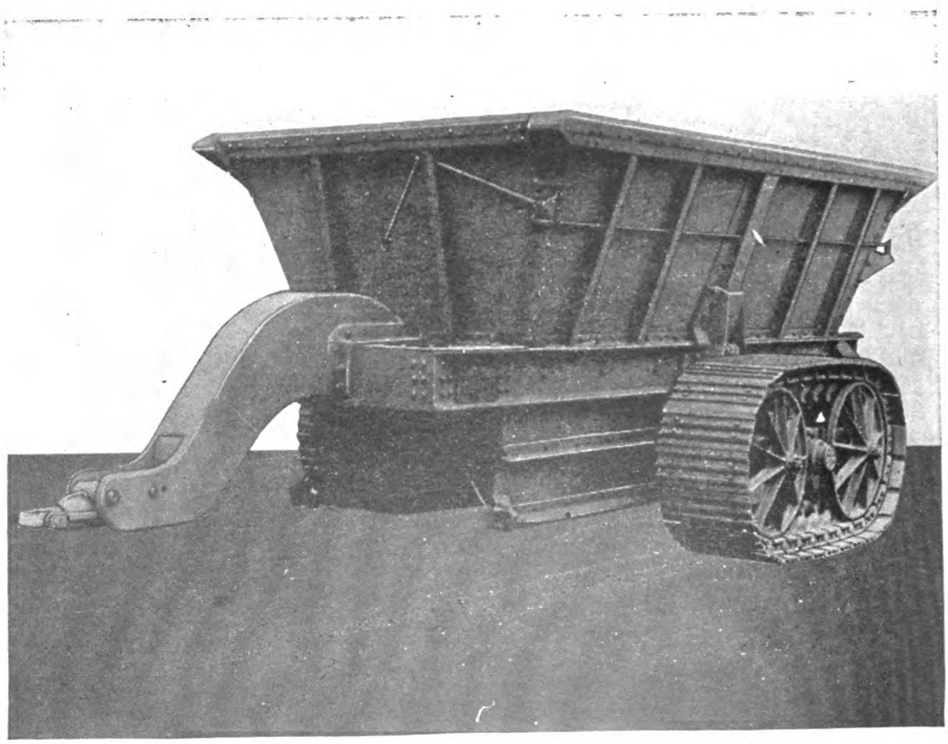


Figure 278. Wagon, dirt or rock, bottom-dump, 11-cubic-yard struck.

APPENDIX I

PERSONNEL AND AIRCRAFT OF ARMY AIR FORCES UNITS

Table XXXIX. Summary of personnel and aircraft in Army Air Forces groups.

Organization	T/O & E No.	Personnel			Airplanes	
		Officers	En-listed	Total	First or initial strength	Second or augmented strength
Air depot group:						
Headquarters and headquarters squadron	1–852	19	150	169	8	—
Depot repair squadron	1–857	10	340	350	—	—
Depot supply squadron	1–858	8	129	137	—	—
Group total	—	37	619	656	8	—
Bombardment group (B–29):						
Headquarters	1–112	25	55	80	—	—
Bombardment squadron (B–29)	1–117–1S	91	393	484	7	7
Total—Headquarters and 4 squadrons	—	389	1,627	2,016	28	28
Bombardment group—heavy:						
Group headquarters	1–112	25	55	80	—	—
Bombardment squadron heavy	1–117	67	351	418	8	12
Total—Headquarters and 4 squadrons	—	293	1,459	1,752	35	48
Bombardment group—medium:						
Group headquarters	1–112	25	55	80	—	—
Bombardment squadron, medical	1–127	67	313	380	13	16
Total—Headquarters and 4 squadrons	—	293	1,307	1,600	57	64
Fighter group—twin-engine:						
Group headquarters	1–12 (cl)	23	50	73	—	—
Fighter squadron, twin engine	1–37 (cl)	38	281	319	25	25
Total—Headquarters and 3 squadrons	—	137	893	1,030	75	100
Fighter group—single-engine:						
Group headquarters	1–12	23	50	73	—	—
Fighter squadron single engine	1–27–C2	38	252	290	25	25
Total—Headquarters and 3 squadrons	—	137	806	1,443	75	100
Tactical Reconnaissance group:						
Group headquarters	1–252	22	57	79	—	—
Tactical reconnaissance squadron	1–267	34	194	228	21	—
Total—Headquarters and 4 squadrons	—	158	833	991	84	—

Table XXXIX. Summary of personnel and aircraft in Army Air Forces groups.—Contd.

Organization	T/O & E No.	Personnel			Airplanes	
		Officers	Enlisted	Total	First or initial strength	Second or augmented strength
Troop carrier group:						
Group headquarters	1-312	19	59	78	--	—
Troop carrier squadron	1-317	83	259	342	13 AP.	--
Total—Headquarters and 4 squadrons	—	351	1,095	1,446	26 GL. 52 AP. 104 GL.	—
Service group (size for 2 combat groups):						
Headquarter and headquarter squadron	1-412	23	136	154	—	—
Service squadron (1 per combat group)	1-417	9	213	222	3	—
Q.M. truck company (1 per combat group)	10-517	3	99	102	—	—
Q.M. company service group aviation	10-437	5	76	81	--	—
Signal company service group (1 per service squadron)	11-237	3	97	100	—	—
Ordnance supply and maintenance company, aviation	9-417	4	75	80	-	—
M.P. company, aviation	19-217	4	100	104	--	—
Total for normal complement for 2 combat groups	1-2	71	1,206	1,277	6	--

APPENDIX II

CHARACTERISTICS OF AIRCRAFT AND AIRCRAFT SIGNALS

1. PURPOSE. The purposes of this appendix are to provide information on current airplane models for which it may be necessary to design suitable accommodations (table XL), and to explain signals for operating and parking aircraft, so engineers working at airdromes may interpret signals correctly and assist in operations when necessary (tables XLI and XLII).

2. OPERATIONAL REQUIREMENTS OF AIRCRAFT. a. Stalling speed. Airplanes in flight are supported and controlled by the flow of air over the wing and tail surfaces. When the speed of the airplane falls below a certain point it stalls; that is, the airplane is inadequately supported and does not respond to the controls. The stalling speed is relative to the air flow and has no reference to ground speed. When an airplane takes off or lands into the wind the air speed is greater than the ground speed. Consequently the necessary ground run is shortened. Modern aircraft design tends toward greater wing loads which make necessary higher landing speeds. These factors create a need for hard-surfaced runways of considerable length.

b. Landing. (1) When a pilot wishes to land he maneuvers his aircraft into position downwind of the runway and, closing his throttle, puts his aircraft into the proper gliding angle. As he nears the ground he flattens his glide and continues to raise the nose until the airplane stalls. If he must pass over any obstacle near the end of the runway, he must land farther in the runway, as any attempt to steepen his angle of glide merely increases his speed so he has to travel further before reaching the stalling point.

(2) When the aircraft first touches the ground it is still partially airborne. Any unevenness of the landing surface, especially an abrupt change of slope, tends to bounce the airplane into the air and cause it to land heavily farther on. As the aircraft runs along, its speed is reduced rapidly and its weight is transferred to the two main wheels. If these are checked suddenly by a soft spot in the runway the airplane may tip onto its nose or wing.

c. Take-off. For an airplane to take off it must exceed stalling speed A considerably greater rate must be reached before it can climb. These phases require a long, straight stretch of clear ground, hence the clear zones in extension of runways.

3. MODEL DESIGNATION OF AIRCRAFT. a. Type designation is indicated by a letter or letters corresponding to the function of that class.

Type	*Designation*
Bombardment (light and dive)	A
Bombardment (medium, heavy, and super)	B
Fighter	P
Observation	O
Observation amphibian	OA
Reconnaissance (photographic)	F
Training (primary)	PT
Training (basic)	BT
Training (advance)	AT (BC)
Transport (cargo and personnel)	C
Autogiro	G
Glider (cargo)	CG
Glider (training)	TG
Rotary wing	R

b. Arabic numerals following the letters indicate the specific model. Letter suffixes differentiate later and improved versions of a model.

c. The prefixes X, Y, and Z in a model designation indicate the respective stages—experimental, service test, and obsolete—in the model's service life. Standard models have no prefix.

d. The designation B–17F illustrates the use of the above symbols. "B" indicates heavy bombardment type; "–17" designates the Boeing plane known as the "Flying Fortress," and "F" marks it as sixth in the series of improvements on the original model. The absence of a prefix to the B shows it to be a standard model in production and in service.

4. TYPES OF AIRCRAFT. a. The principal combat types used by the U. S. Army are as follows:

(1) *Fighter airplanes* are fast, highly maneuverable craft designed for aerial combat. Some models can climb almost vertically. Fighters normally operate at high altitudes and in squadron formation. The engine sound is high-pitched and varies extremely in tone and volume during such maneuvers as climbing and diving.

(2) *Bombardment* airplanes are classified as super, heavy, medium, light, and dive. The engine sounds generally are characterized by a fairly deep pitch, moderately heavy volume, and steady tone and rhythm.

(*a*) *Super, heavy,* and *medium bombers* are designed to carry heavy bomb loads great distances. En route to and from their objectives they operate in formation at high altitudes.

(*b*) *Light and medium bombardment* airplanes are designed to attack material objectives of light construction, airdromes, routes of communication and supply, and personnel concentrations. They are fast, maneuverable craft of

1 PROPELLER HUB
2 PROPELLER BLADE
3 ENGINE
4 ENGINE COWL
5 EXHAUST-COLLECTOR RING
6 FUEL AND OIL LINES
7 ENGINE CONTROLS
8 RUDDER CONTROL
9 ELEVATOR AND AILERON CONTROL
10 ACCESSORY COWL
11 RETRACTABLE LANDING GEAR
12 PILOT'S INCLOSURE
13 OIL TANK
14 CABIN
15 AILERON
16 WING
17 AILERON TAB
18 FUEL TANK
19 FRONT SPAR
20 REAR SPAR
21 LEADING EDGE
22 INTERSPAR SECTION
23 TRAILING EDGE
24 METAL SKIN
25 FRAME OR BULKHEAD
26 NOSE RIBS
27 AILERON RIBS
28 STRINGER
29 WING TIP
30 FUSELAGE
31 FAIRING
32 LONGERON
33 INTERMEDIATE FRAME
34 TAIL WHEEL
35 ELEVATOR
36 STABALIZER
37 VERTICAL FIN
38 RUDDER
39 RUDDER TAB
40 ELEVATOR TAB

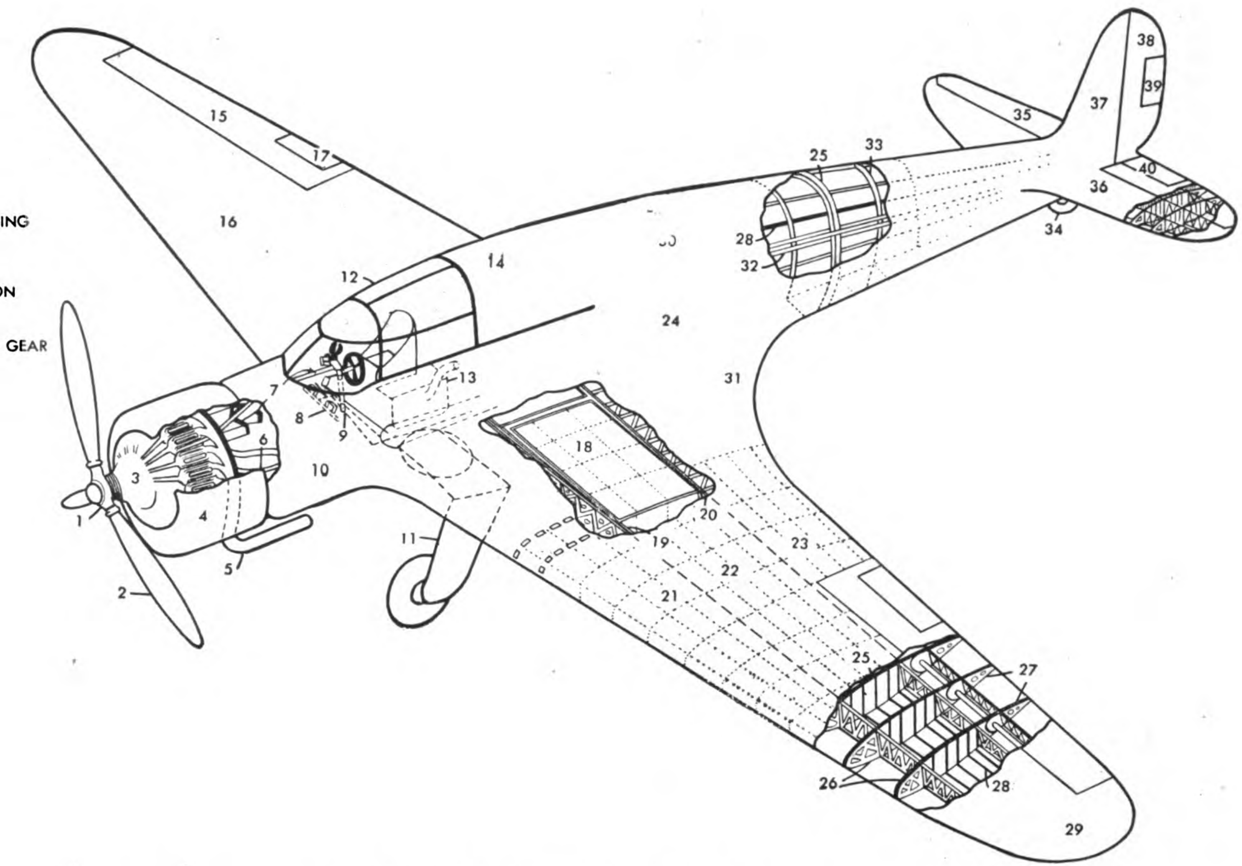


Figure 279. Principal structural elements of single-engine airplane.

medium size. Since light bombers operate at low altitudes and are susceptible to small-arms fire, troops must be able to identify friendly airplanes quickly and accurately.

(*c*) *Dive bombers* are designed to launch a heavy bomb at a well-defined target by diving steeply from a considerable height. Necessary special construction makes them relatively slow, and easy prey for fighters. Normally they are used to support advancing ground troops in zones where friendly fighters dominate the air.

(3) *Observation airplanes* are designed to carry two men at a slow rate low over friendly territory. Besides observation their mission includes communication and artillery fire adjustment. Ground troops should be able to recognize this type instantly.

b. Transport and training airplanes are the principal noncombat types employed by the Army.

(1) *Transport* airplanes are designed to move loads of personnel and supplies, normally over friendly territory. They are large, slow craft, fly at moderate heights, and resemble peacetime commercial airliners.

(2) *Training* airplanes rarely will be seen in the theater of operations.

c. For further information on characteristics of aircraft see FM 30–30.

5. SIGNALS. For an explanation of signals used between control tower and airplane and for signals used in parking aircraft see tables XLI and XLII.

Table XL. Dimensions of aircraft for design of facilities.

Model	Weight, gross, loaded (pounds)	Wing span (feet)	Wing span (inches)	Length over-all (feet)	Length over-all (inches)	Height at rest (feet)	Height at rest (inches)	Height wing tips, approximate (feet)	Height wing tips, approximate (inches)	Tread center to center of tire (feet)	Tread center to center of tire (inches)	Number of engines	Type landing gear	Minimum turning radius (calculated) (feet)	Minimum turning radius (calculated) (inches)
Pursuit type: P-38	21,000	52	0	37	10	12	10	9	0	16	6	2	Tricycle	25	7
P-39	9,200	34	0	30	2	11	10	5	6	11	4	1	Tricycle	23	1
P-40	12,000	37	4	33	4	12	4	7	6	8	2	1	Tailwheel	22	6
P-47	15,000	40	9	36	1	14	2	7	0	15	6	1	Tailwheel	26	10
P-51	11,000	37	0	32	3	13	8	5	6	11	10	1	Tailwheel	22	1
P-63	8,900	38	4	32	8	12	3	5	6	14	7	1	Tricycle	25	4
Attack and light bomber: A-20	27,000	61	4	48	0	18	1	10	0	17	0	2	Tricycle	32	3
A-24	9,137	41	6	32	8	12	11	6	9	10	6	1	Tailwheel	28	3
A-25	12,976	49	9	36	8	13	2	7	6	16	0	1	Tailwheel	25	11
A-26	32,000	70	0	50	6	18	6			19	7	2	Tricycle		
A-28 (A-29)	20,000	65	6	44	4	11	11			15	4	2	Tailwheel		
A-31	14,375	48	0	39	9	12	10	9	5	11	4	1	Tailwheel		
A-35	15,838	48	0	39	9	11	6	9	5	11	4	1	Tailwheel	35	0
A-36						13	8	5	6	11	10	1	Tailwheel		

Table XL. Dimensions of aircraft for design of facilities.—Continued.

Model	Weight, gross, loaded (pounds)	Wing span (feet)	Wing span (inches)	Length over-all (feet)	Length over-all (inches)	Height at rest (feet)	Height at rest (inches)	Height wing tips approximate (feet)	Height wing tips approximate (inches)	Tread center to center of tire (feet)	Tread center to center of tire (inches)	Number of engines	Type landing gear	Minimum turning radius (calculated) (feet)	Minimum turning radius (calculated) (inches)
Bombardment:															
B-17	64,000	103	10	73	10	19	3	11	4	21	2	4	Tailwheel	43	6
B 24	64,000	110	0	66	4	18	0	11	6	25	8	4	Tricycle	41	6
B 25	35,000	67	6	53	0	15	9	9	0	19	4	2	Tricycle	38	2
B-26	38,200	65	0	58	3	19	10	11	0	22	0	2	Tricycle	41	7
B 29 *	130,000	141	3	99	0	27	9	13	0	31	6	4	Tricycle	about 50 ft.	
Cargo type:															
C 45	8,500	47	8	34	3	9	4	6	0	12	11	1	Tailwheel		
C 46	56,000	108	0	76	4	22	0	14	0	26	0	2	Tailwheel	56	6
C 47 and C-53	36,500	95	0	64	6	17	0	9	6	18	6	2	Tailwheel	41	2
C-54*	76,000	117	6	93	10	27	6	14	0	24	8	4	Tricycle	59	7
C-60	25,000	65	8	49	10	12	0	10	0	15	4	2	Tailwheel	55	9

* Dual wheels.

Table XLI. Hand signals for airplane operation and movement on the ground.

Signal	Meaning
Flagman waving black and white checkered flag.	Flagman directing pilot to parking crewman.
Parking crewman walking backwards facing plane, both arms upraised.	Hands motioning pilot "follow me." Used to direct airplane to berth.
Signal with right hand; left hand stationary, palm toward pilot.	Right turn.
Signal with left hand; right hand stationary, palm toward pilot.	Left turn.
Wigwag hands across each other, scissors fashion, at face level.	Stop
Forefinger drawn across throat.	"Cut" ignition switch; parking completed.
Flagman 100 feet or more from parking line waving checkered flag.	Guiding pilot from parking line to open area.

Table XLII. Light signals for communication between control tower and aircraft.*

From control tower to aircraft.

Signal	Meaning		
	Airplane in flight	Airplane taxiing	Airplane in take-off position
Green light.	Clear to land.	Continue taxiing.	Clear for take-off.
Flashing red light.	None.	None.	Return to line.
Red light.	Do not land. Stay clear of field and continue circling.	Stop immediately.	Do not take off; wait.

From aircraft to control tower.

Signal	Meaning
Landing light on.	Desire to land. (This signal should be acknowledged by control tower.)
One flash of landing light.	Acknowledge visual signal from ground.
Series of flashes of landing lights.	If floodlights are off, turn on floodlights. If floodlights are on, turn off floodlights.

* Airdrome control towers have a traffic-control lamp designed to show either a red or a green light.

APPENDIX III

SOIL AND AGGREGATE SAMPLING AND TESTING PROCEDURES

1. REPRESENTATIVE SAMPLES. Each sample for examination, identification, and tests must be representative of the deposit or supply from which it comes. Validity of all interpretations, conclusions, and designs based upon test results depends upon the accuracy with which the sample represents the whole.

2. SAMPLING. a. *Test pits and gravel banks* are sampled by channeling. A cloth or tarpaulin to collect the sample is placed at the bottom of the pit next to the bank. A hand shovel or pick is used to dig a vertical channel from top to bottom of the face being sampled until 50 or 100 pounds of material are collected. Overburden that will be wasted is not included. The collected sample is identified, tagged, and placed in a bag. Generally, sand and earth deposits can be sampled satisfactorily by auger holes, provided overburden is excluded or kept in separate containers.

b. *Aggregate* already in bins is difficult to sample properly. Better samples may be taken as aggregate spills from conveyor belt into bin by passing a bucket completely through the stream of falling material. Several samples should be taken in this manner and combined for subsequent reduction by quartering. Samples also may be taken from the spout or loading chute as material is discharged from bins into trucks.

c. *Stock piles* may be sampled by uniform surface channeling, as are test pits. The channel must extend from bottom to top because stock piles always have a preponderance of coarse aggregate at the outside bottom edges and a deficiency of coarse aggregate at the top. Stock piles built up in layers by truck dumping may be sampled by digging well into the pile from the top.

d. Windrows are sampled by combining equal amounts selected from top, center, and bottom, well within the stack each time.

e. *Samples* from material in place on the runway are obtained by combining spot samples selected over the area.

3. QUARTERING SAMPLES. a. Frequently it is necessary to reduce a large representative sample to a smaller convenient size without sacrificing representation. The process is called *quartering.* The total collected sample first is piled in a cone on a canvas or tarpaulin, each shovelful going to the center of the cone and being allowed to run down equally in all directions to mix the sample. The cone then is spread out in a circle by walking around the pile and gradually widening the circle with a shovel until the material is spread to a uniform thickness. The flat pile then is marked into quarters. Two opposite quarters are discarded. The material in the remaining quarters again is mixed by shoveling the material into another conical pile, taking alternate shovelfuls from each quarter. The process of piling, flattening, and rejecting two quarters is continued until the sample is reduced to the desired size.

b. Small samples are quartered by essentially the same process but are mixed by rolling instead of by piling. The total collected sample is placed on the canvas or tarpaulin. Each corner of the canvas is lifted in turn and pulled back over the canvas as if preparing to fold it on a diagonal. After thorough mixing the sample is flattened and quartered as before. This procedure is especially useful in the laboratory for selecting small representative test samples.

4. LABORATORY TESTS. The laboratory tests performed to determine physical characteristics and constants of subgrade and base materials are: sieve analysis, moisture content determination, compaction test (modified A.A.S.H.O. method), density test, and California bearing ratio. Fine-grained soils may require a wet analysis in addition to sieve analysis. Extent of the testing program will depend upon types of soil and experience of the soil technician. All classification tests will not be required after the technician becomes thoroughly acquainted with the soils of a locality. Significance and procedure of classification tests are described in the following paragraphs.

5. GRADATION. Grain-size distribution of a soil is determined either by sieve analysis or by a combination of sieve and wet (sedimentation) analysis. Procedures used to determine gradation are as follows:

a. Sieve analysis. A sieve analysis is used to determine gradation of material containing a substantial portion of gravel and sand sizes. *If the sample has little fine material,* so dry sieving will give good particle separation, the procedure is as follows:

(1) Select a representative sample weighing 200 to 500 grams, depending upon the percentage of gravel particles.

(2) Dry the sample and record the dry weight.

(3) Put the dry sample in a stack of sieves consisting of 1-inch, ¾-inch, ¼-inch, Nos. 4, 10, 40, 60, 100, and 200, and pan. Place the cover on the stack and shake the stack vigorously with a horizontal rotating motion and occasional jarring on a *buffer* or *pad* until the particles have been separated.

NOTE. Sieves may be added or omitted from this series as needed or desired. Because the No. 200 sieve is delicate and easily damaged it is always protected by having a coarser sieve such as No. 40 or No. 60 on top of it.

(4) Starting with the top sieve (largest) determine the weight of particles on each sieve and in the pan. Record the results as in table XLIII. Save each part of the sample until a check has been made by comparing the sum of the weights with the original dry weight (see (2) above).

(5) Results are computed as in table XLIII and plotted as in figure 280, which is 5-cycle semilogarithmic paper with the abscissa plotted as "sieve opening" or "grain diameter" in millimeters or inches, and the ordinate as "percent finer." (See table LXII for sieve dimensions.)

Table XLIII. Sample identification.

Sieve	Weight in grams retained on each sieve	Percent retained by weight	Cumulative percent finer than each sieve
1-inch	35	7	93
½-inch	85	17	76
¼-inch (No. 3)	90	18	58
No. 4	45	9	49
No. 10	75	15	34
No. 40	95	19	15
No. 100	40	8	7
No. 200	15	3	4
Passing No. 200	20	4	..
Total	500	100	

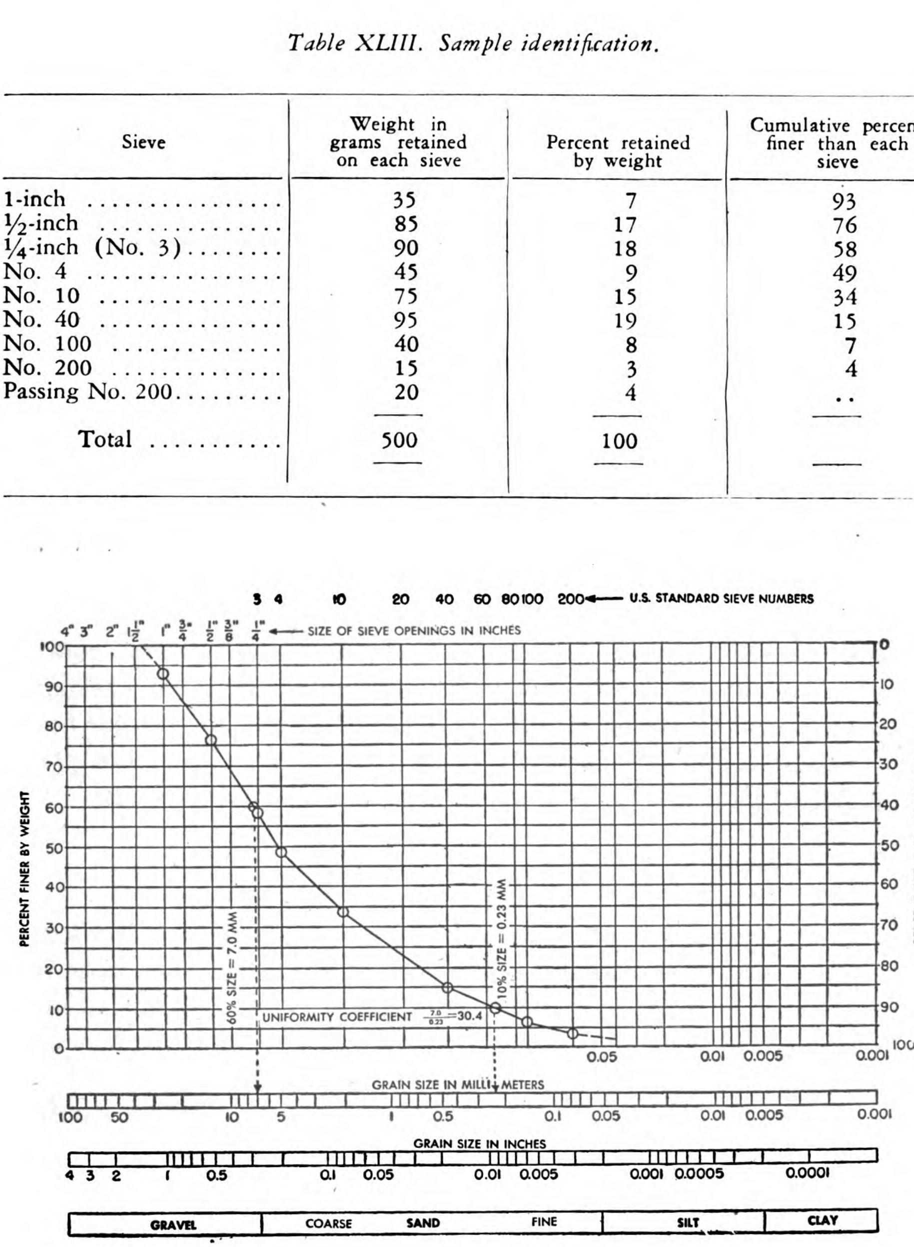


Figure 280.

(6) If the sample has such a proportion of fine material that dry sieving will not be accurate, prewashing is necessary. The procedure then is as follows:

(*a*) Select a representative sample as above.

(*b*) Dry the sample and record the dry weight.

(*c*) Wash the sample on a No. 100 sieve, being careful not to lose any of the material retained on the sieve.

(*d*) Dry the portion retained on the No. 100 sieve and record its weight. The difference between the original dry weight ((2) above) and the dry weight after washing is recorded as the weight passing No. 100 sieve.

(*e*) Shake the washed and dried sample through sieves as above.

(*f*) Weigh and record the results as above. The sum of all weights, including the weight passing No. 100 from (4) above, should check with the original dry weight in (2) above.

(*g*) Compute and plot the results as noted in (5) above.

b. Wet analysis (sedimentation analysis). This is not a routine test. Its use will be required only for special studies of subgrade soils such as frost-action characteristics. Laboratory equipment for this test is included in depot stock, but not in the aviation battalion set No. 1. Wet analysis is used to determine gradation of fine soils composed of particles passing the No. 100 sieve and is based on the fact that soil grains of the same material but of different sizes will fall through water at different velocities. Equipment required includes a 1,000-cubic-centimeter graduated cylinder with a side petcock 15 to 25 centimeters below the 1,000-cubic-centimeter graduation. A small representative portion of the soil sample is uniformly dispersed in water in the graduate and set in a vertical position. At selected intervals of time, density of the suspension at the level of the petcock is determined by removing part of the suspension. From this density and the density at the beginning, percentage of soil remaining in suspension at the depth of the petcock below the water surface can be computed by Stokes' law. Velocity of fine grains of soil falling through a water medium, according to Stokes' law, is:

$$V = \frac{2}{9} \times \frac{S - So}{n} \times \left(\frac{d}{2}\right)^2$$

S and So are specific gravities of soil and liquid, respectively, n is viscosity of the liquid, and d the diameter of the soil grain assumed to be spherical. For purpose of a wet analysis, sufficiently accurate results can be obtained by using the formula:

$$V = 9{,}000\, d^2$$

where d is in centimeters and V in centimeters per second. This formula is derived from Stokes' law by substituting the following:

$S = 2.67$

$So = 1$ (water)

$n = 0.0000103$ gram-sec. per sq. cm. (water at 20° C.)

Using the formula ($V = 9{,}000\ d^2$), curves on figure 281 have been drawn showing distances through which different-size soil particles will fall in a given time. The following procedure is used:

(1) Select a representative sample of the soil passing a No. 100 sieve.

(2) Thoroughly dry and weigh 50 to 100 grams of the sample.

(3) Disperse the specimen in water in a 1,000-cubic-centimeter graduate cylinder and fill the cylinder to 1,000-cubic-centimeters gradation. It is necessary to disperse the soil thoroughly by stirring or shaking, taking care not to spill any of the suspension. Water should be at room temperature.

(4) If the soil particles flocculate (form clusters), from 5 to 10 cubic centimeters of sodium silicate should be added during the dispersion process.

(5) Shake the cylinder to produce a uniform suspension and set in a vertical position at a noted time. Thereafter the cylinder should not be disturbed. The temperature of the cylinder should be maintained reasonably constant near room temperature.

(6) Measure in centimeters the distance L from the center of the petcock to the water surface.

(7) Determine from the curves in figure 281 the time required for a certain size particle to fall through the distance L.

(8) After the required period draw off through the petcock approximately 100 cubic centimeters of suspension.

(9) Determine the dry weight of the soil in the drawn-off suspension by evaporating the water and weighing the soil residue.

(10) Compute the percentage of soil finer than the grain size selected in (7) above by the following formula:

$$P = \frac{V_1}{W_1} \times \frac{W_2}{V_2} \times 100$$

In which—

W_1 = Initial total dry weight of soil in grams.

V_1 = Initial volume in cubic centimeters of suspension.

W_2 = Dry weight in grams of soil in suspension drawn off through petcock.

V_2 = Volume in cubic centimeters of suspension drawn off through petcock.

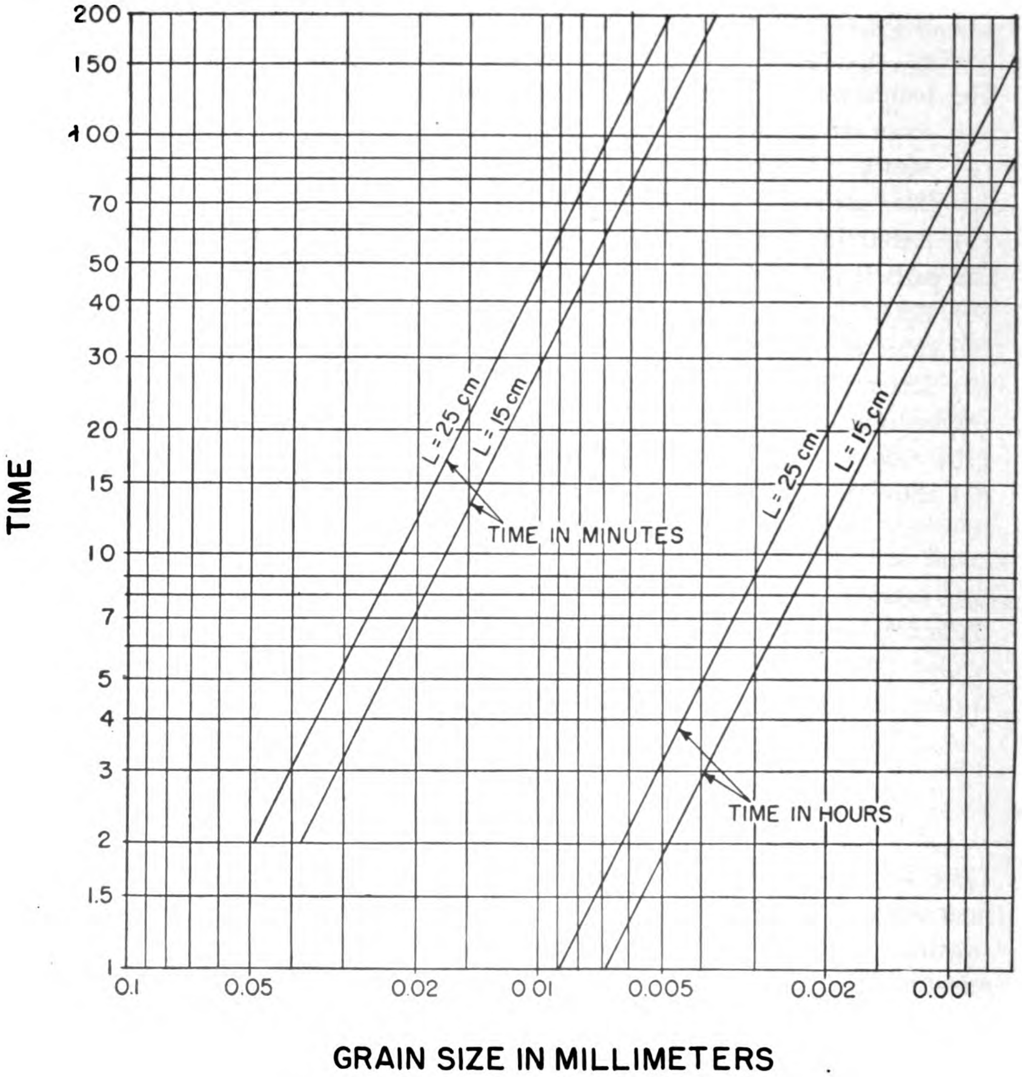
(11) Repeat steps in (6) through (10) above to determine the percentage finer than particles of any other size. Usually the percentage finer than three sizes may be determined. It should be noted that L changes for each determination, but W and V_1 are constant.

(12) Plot the data as noted in a(5) above.

c. Combined analysis. Combined analysis is used when it is desired to have a complete grain-size distribution curve for materials containing gravel, sand, silt, and clay sizes. The soil usually is washed through a No. 100 sieve to separate fine and coarse fractions. Separation for some soils may be obtained satisfactorily by dry sieving. Gradation of material passing the No. 100

sieve is obtained by wet analysis, as described in **b** above, and gradation of that retained on the sieve by sieve analysis, as described in **a** above. Results are combined to determine the percentage of grains finer than a given size, based on the total dry weight as illustrated in table XLIV. Results are plotted as noted in **a**(5) above. (See fig. 282.)

CURVES SHOWING RELATION BETWEEN GRAIN SIZE, TIME AND SETTLEMENT DISTANCE BASED ON STOKES LAW FOR AVERAGE TESTING CONDITIONS.



L=SETTLEMENT DISTANCE IN CENTIMETERS

Figure 281.

Table XLIV. Sample identification.

Sieve	Weight in grams retained on each sieve	Percent retained by weight	Cumulative percent finer than each sieve
Sieve analysis:			
1-in.	0	0	100
½-in.	100	20	80
¼-in. (No. 3)	85	17	63
No. 4.	35	7	56
No. 10.	35	7	49
No. 40.	25	5	44
No. 100.	20	4	40
Passing 100.	200	40	
Total.	500	100	

Sieve	Distance (L) (centimeter)	Time		Dry weight, (grams)	Percent finer
		Minutes	Seconds		
Wet analysis:					
Finer than 0.03-mm.	25	5	20	1.60	32
Finer than 0.01-mm.	20	38		1.10	22
Finer than 0.004-mm.	15	170		0.65	13
Original sample.	—	—		50.0	

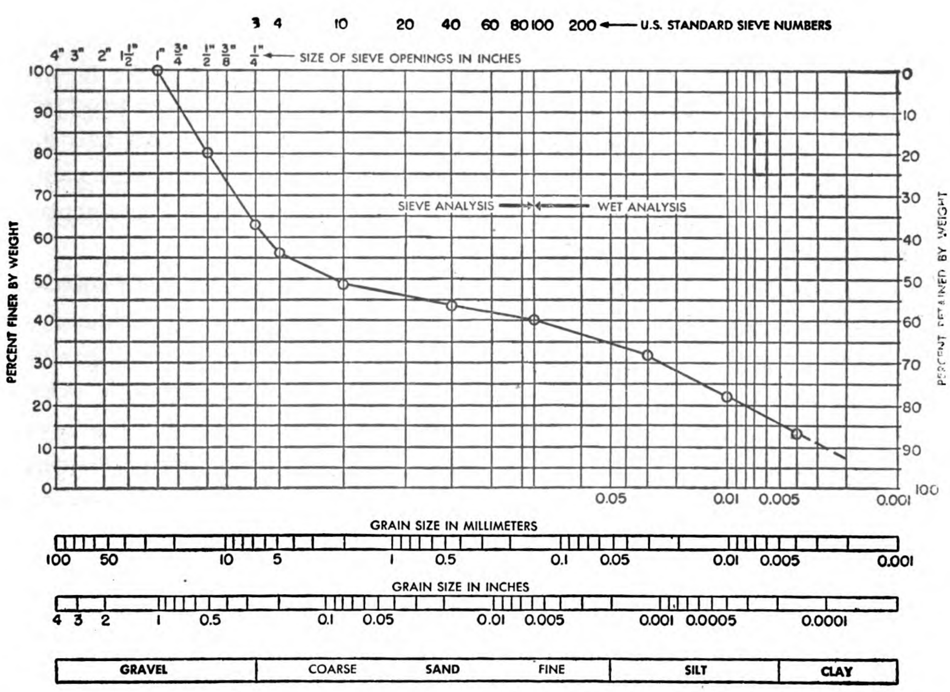


Figure 282.

d. Uniformity coefficient. The coefficient of uniformity, defined as the 60-percent size divided by the 10-percent size, is an index of the gradation of a soil. For example, the soil whose gradation is plotted in figure 1 has a uniformity coefficient of 7.0/0.23=30.4. *Uniformly graded* materials have coefficients of uniformity less than 5, and *well-graded* materials more than 20. Between these two limits a soil may have properties of a well-graded or of a uniform material, depending upon the shape of the gradation curve.

6. MOISTURE-CONTENT DETERMINATION. Moisture contents of natural and compacted subgrade, compacted fill, and base-course materials should be determined for the purpose of design and for control of compaction during construction. Moisture-content determinations are also required for the California bearing ratio, expansion, density, compaction, liquid limit, and plastic limit tests. Moisture content is expressed in percentage of dry weight of the soil. In general, determinations are made by placing a representative specimen of the wet soil in a metal container and thoroughly drying the specimen in an oven. If the soil is free from organic and other combustible matter, the specimen may be dried over a fire. The wet weight of the specimen prior to heating and the dry weight having been determined, the moisture content may be computed by the formula:

$$P = \frac{W_w - W_d}{W_d} 100 \text{ (in percent)}$$

P = Moisture content in percent of dry weight
W_w = Wet weight of sample
W_d = Dry weight of sample

7. LIQUID LIMIT (LL). a. Liquid limit is the moisture content expressed as a percentage by weight of oven-dry soil at which a remolded soil will just begin to flow when jarred slightly. Liquid limit in conjunction with plastic limit is of great value in proper identification and classification of fine-grained soils in a remolded state (par. 16 of this app).

b. The device used to determine the liquid limit consists of a mechanism for producing uniform blows on the bottom of a dish. The test should be performed by using a representative sample of the fraction of soil passing the No. 40 sieve. Fifty to eighty grams of the sample are thoroughly mixed with water to form a heavy paste and placed in the dish. The soil is grooved with a special tool which is drawn through the soil specimen along a diameter of the cup passing through the center of the hinge. In cutting the groove the tool should be held perpendicular to the surface of the dish. Shoulders of the tool should remove soil for a length of about 1½ inches when the dish is filled properly. A clean groove generally can be made in clays with one stroke of the tool. In silty soils, however, it may be necessary to cut the groove with several strokes of the tool or with a spatula, using the tool to check the dimensions.

c. After the soil is placed in the dish and the groove properly formed the crank of the liquid-limit device is turned approximately two revolutions per second. The number of shocks required to close the bottom of the groove for a distance of half an inch is determined. Part of the specimen is placed in a metal container and the moisture content is determined as described in paragraph 6 of this appendix. The above procedure is repeated at various moisture contents. A graph is plotted showing the relation between moisture content and number of shocks required. The water content corresponding to 25 shocks, obtained from the graph, is defined as the liquid limit. If plotted on semilogarithmic paper, the graph will be a straight line.

8. PLASTIC LIMIT (PL). a. Plastic limit is the lowest moisture content expressed as a percentage of the dry weight at which soil can be rolled into threads of 1/8-inch diameter without crumbling. Plastic limit is the moisture content at which cohesive soils pass from a semi-solid to the plastic state. Thus, if natural moisture content of a soil is less than the plastic limit, the soil possesses relatively high stability.

b. The test is performed on a representative sample of the soil fraction that passes the No. 40 sieve. A sample of the soil is mixed thoroughly with water to form a plastic mass at a moisture content somewhat above the plastic limit. A specimen about the size of a 1/2-inch cube is removed from the plastic sample and rolled on a flat nonabsorbent surface with the palm of the hand, forming a roll about 1/8 inch in diameter. If crumbling does not occur at that moisture content, fold, knead, and reroll as before. Repeat this process until water content is reduced to the plastic limit, which is reached when crumbling occurs as soil is rolled out to a diameter of about 1/8 inch. Moisture content of the sample at the plastic limit is determined as stated in paragraph 6 of this appendix. Some soils cannot be rolled into threads at any moisture content. Such soils do not have a plastic limit as defined above. Test results are reported as nonplastic (NP).

9. PLASTICITY INDEX (PI). Plasticity index is the difference between liquid limit and plastic limit. It is determined by taking the numerical difference between the two values. For example, if the liquid and plastic limits of a soil are 28 and 24, respectively, the plasticity index is 4. A cohesive soil with a low plasticity index has better stability than one with a high value. Nonplastic (NP) soils that have no plastic limit are considered to have a plasticity index of zero.

10. LABORATORY COMPACTION AND OPTIMUM MOISTURE TEST (MODIFIED A.A.S.H.O.). a. The density to which a soil may be compacted with a given compaction effort depends upon the moisture content. Moisture content at which the greatest density is obtained with a given compaction effort is termed *optimum moisture*. It should be noted that optimum moisture is not a constant for a given soil but is variable, depending upon the amount of compaction effort. Optimum moisture decreases with an increase of compaction effort and in general is such that air content of the soil (unfilled voids) is from 2 to 8 percent by volume, depending upon the characteristics of the soil.

b. In runway pavement construction it is desirable to compact subgrade fill, upper zones of subgrade cuts except in clay soils, and base-course materials to as great a density as is practicable, in order to obtain greatest stability and prevent detrimental settlements. It has been found the maximum density that can be obtained in actual construction, using ordinary heavy compaction equipment, is duplicated closely in the laboratory by the modified A.A.S.H.O. test procedure.

c. Special equipment required to make the laboratory compaction test consists of a Proctor cylinder and a metal tamper with a striking face 2 inches in diameter, weighing 10 pounds. The Proctor compaction cylinder is a metal cylinder having an internal diameter of 4 inches and a height of 4.59 inches. Its volume is one-thirtieth of a cubic foot. The cylinder has a removable baseplate and a removable extension of the cylinder having the same internal diameter as the cylinder and approximately 2½ inches in height.

d. Procedure of the laboratory compaction test (modified A.A.S.H.O. method) is as follows:

(1) Air-dry a sample weighing approximately 6 pounds and remove all material not passing a ¼-inch sieve.

(2) Determine and record tare weight to 0.05 pound of the Proctor cylinder with attached baseplate but without the extension.

(3) Thoroughly mix the sample with a sufficient quantity of water to obtain a damp mixture, taking care not to add too much water.

(4) With the extension attached, fill the Proctor cylinder in five layers, compacting each layer to approximately 1-inch thickness by dropping the tamper 25 times. The height of drop should be 18 inches above the soil and blows should be distributed over the soil-layer surface.

NOTE. When using this compaction equipment for density and control tests for soil-cement construction, the height of fall of the tamper should be restricted to 6.5 inches to get tests results corresponding to the A.S.T.M. method of test usually employed for soil-cement work.

(5) Carefully remove the extension and level off the top of the soil with a straightedge.

(6) Determine the unit wet weight (U_w) of the compacted soil in pounds per cubic foot.

(7) Remove the soil from the cylinder, extract from the center a sample weighing about 100 grams, and determine its moisture content (P), as in paragraph 6 of this appendix.

(8) Compute the unit dry weight (U_d) of the compacted soil, using data in (6) and (7) above.

$$U_d = \frac{100\,U_w}{100 + P} \text{ (in pounds per cubic foot)}$$

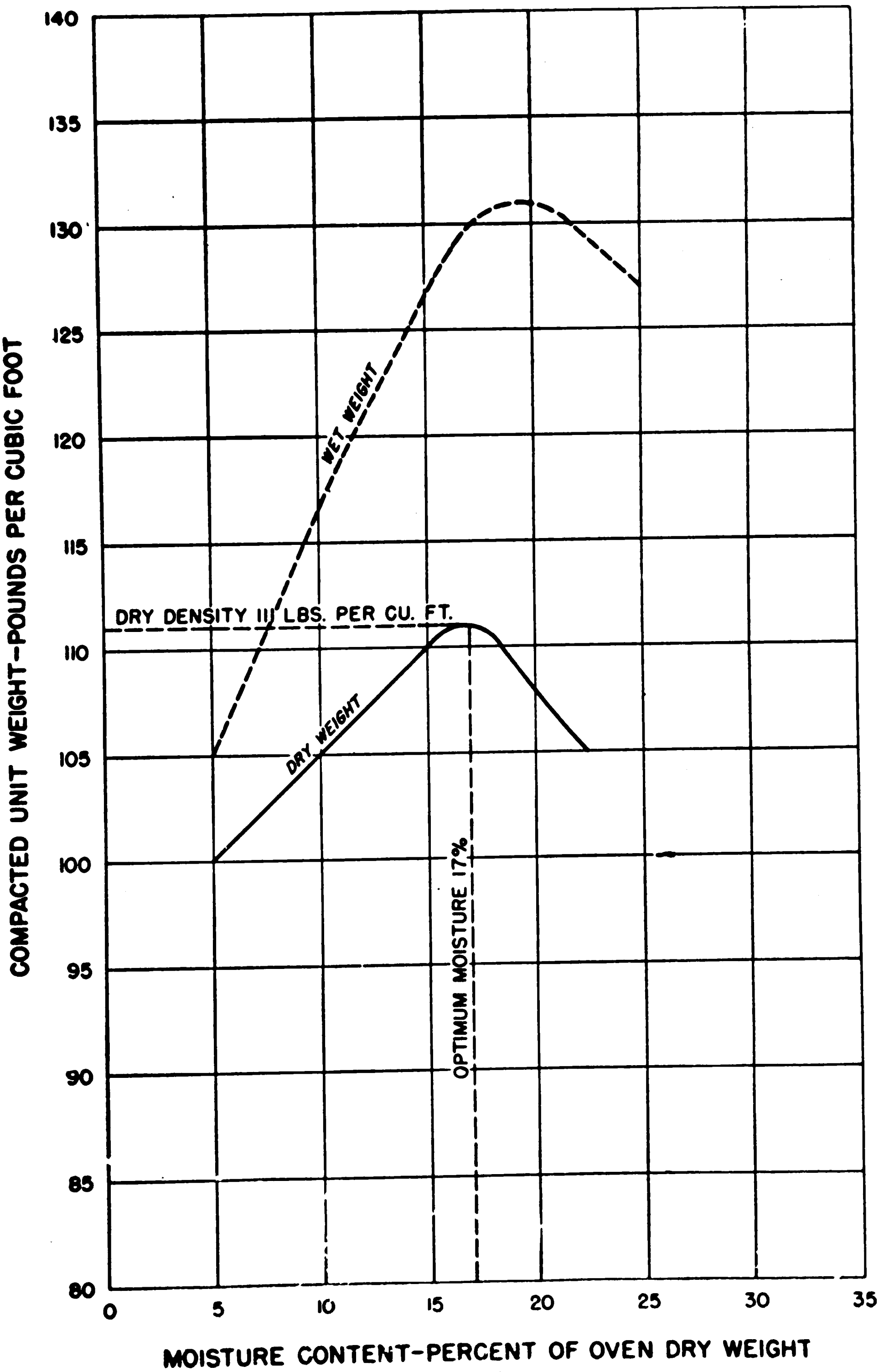


Figure 283. Unit weight curves of soil.

(9) Thoroughly remix the remainder of the sample, adding sufficient water to increase the water content from 1 to 2 percent, and repeat the above steps.

(10) Repeat the procedure until points beyond the maximum density have been obtained.

(11) From the density thus obtained prepare a curve, as in figure 283, showing the relation between moisture content and unit weights, dry and wet (unit weight as ordinate). The peak of the curve defines the optimum moisture and maximum density (max. U_d) that should be used for compaction control during construction.

e. Difficulties may be encountered with the above procedure if the soil is uniform fine sand. A soil must contain sufficient binder or be sufficiently well-graded to prevent upheaval during blows of the tamper. Otherwise, initial stability should be produced by lighter blows before the standard blows are applied.

f. Only material passing the 1/4-inch sieve is used in the test. Thus, optimum moisture and unit dry weight obtained from the test are not representative of the total material if it contains any considerable amount of gravel particles. For control during construction it is necessary to determine unit weight and moisture content only of material passing the 1/4-inch sieve. Stones greater than 1/4 inch should be removed from specimens used for moisture-content determinations. Unit weight can be determined by adjusting the unit weight of the total sample according to percentage by weight and volume of particles greater than 1/4-inch diameter in the soil. However, for predominantly gravelly soils this correction is not reliably accurate.

11. CALIFORNIA BEARING RATIO (CBR) AND SWELL TEST. a. The California Division of Highways has developed an empirical method for designing flexible highway pavements which employs a test termed "bearing ratio." This is a measure of the relative stability of soils and base material. The empirical data have been extended for use in airdrome pavement design, for which purpose some modifications of the original test procedure have been found necessary. Bearing ratio is the load intensity required to produce 0.1-inch penetration of a piston 1.954 inches in diameter (3 square inches) into a soil divided by the load intensity required to push the same piston 0.1 inch into a standard sample of compacted crushed stone. The samples usually are saturated prior to the penetration test. Bearing ratio is expressed as a percentage. For designing thickness of various base courses, bearing ratio should be determined for all subgrade soils and base-course materials. *Soils should be tested at a density comparable to that obtained in construction* (see par. 134 and par. 12 of this app). In cases where moisture conditions are favorable and the airdrome subgrade will not accumulate moisture approaching a saturated condition, samples should be tested at a moisture content approximating true conditions during the time the airdrome is used. In all other cases samples are tested in a saturated condition.

b. Equipment consists of a metal cylinder similar to a Proctor cylinder (see par. 10 of this app.) except it is 6 inches in diameter; buckets in which the soil sample is saturated; a loading device to force the piston into the soil; and attachments.

c. The following procedure is used to determine CBR of remolded compacted samples where field compaction is in accordance with paragraphs 122d and 134.

(1) Remove all material over ¾ inch in size and replace with an equal proportion of material passing the ¾-inch sieve and retained on the No. 4 sieve.

(2) Conduct applicable control compaction tests, using the 6-inch mold and the sample as prepared in (1) above. For cohesionless soils (P.I. less than approximately 2), which will compact readily under traffic, the modified A.A.S.H.O. method (par. 10 of this app.) should be used to determine the optimum moisture and density. For other soils compaction tests should be made to determine the optimum moisture for 95 percent density as obtained by the modified A.A.S.H.O. method and the number of hammer blows required to produce that density. To determine the optimum moisture and number of blows several compaction tests with various numbers of blows should be made and the results plotted.

(3) Clamp to the base plate the mold with fitted extension collar and insert the spacer disk over the base plate.

(4) Compact sample in test mold. Cohesionless soils (*PI* less than approximately 2), which will compact readily under traffic, should be placed at optimum moisture to the maximum weight obtained by the modified A.A.S.H.O. method. All other soils should be compacted at optimum moisture content (for 95 percent density) to a density equal to 95 percent of that obtained by the modified A.A.S.H.O. method, using the number of blows as determined in step (2) above. To obtain accurate results great care must be used to insure that the molding moisture content exactly equals the optimum moisture content. The molding moisture content for the compacted density never should be greater than the optimum.

(5) Remove collar, trim sample, place screen over top of sample, and clamp perforated base plate to top of test mold.

(6) Invert test mold, remove base plate and spacer disk, and determine density of sample.

(7) Place adjustable stem and plate on the surface of the sample and apply annular weight to produce an intensity of loading equal to the weight of the base material and pavement (if a pavement is to be constructed), which will overlie the soil in the prototype represented by the sample, except that a weight of less than 10 pounds shall not be used. The weight applied must be estimated and, if it does not produce the intensity present in the final design, the test should be repeated. On fine-grained soil it is desirable to place filter paper on the soil surface before placing the plate.

(8) Immerse the test mold in water for 4 days, with the top of the mold slightly below the water surface. During the soaking period the percent expansion should be determined and recorded. It may be necessary to saturate some low plastic soils from the bottom only to prevent a soft spongy surface condition.

(9) Remove the free surface water and allow drainage downward for 15 minutes. The object is to remove all free water from the top of sandy samples so a quick condition will not occur under the piston when the sample is penetrated rapidly. It may be necessary to permit a longer drainage period for some fine sandy soils. In removing the free water from the surface care should be taken not to change the density conditions. After drainage remove the annular weights, stem, and plate.

(10) Apply to the surface an annular weight equivalent to that stated in step (7) above, except that the weight shall not exceed 30 pounds.

(11) Seat the penetration piston with a 10-pound load and set the dial gauge to zero. The purpose of a 10-pound load before starting the penetration test is to insure satisfactory seating of the piston, and should be considered as the zero load when determining stress-strain relations. The area of the face of the penetration piston is 3 square inches.

(12) Apply the load on the penetration piston so the rate of penetration is approximately 0.05 inch per minute. Obtain load readings at 0.025-, 0.050-, 0.075-, 0.1-, 0.2-, 0.3-, 0.4-, and 0.5-inch deformation.

(13) Determine the moisture content in the upper 1 inch and for the entire depth of the sample.

(14) Determine the relative bearing value in percent for 0.1-inch increments of penetration, compared with the following standard load (penetration loads for crushed stone):

Penetration (inches)	*Standard load (pounds)*	*Standard load (pounds per square inch)*
0.1	3,000	1,000
0.2	4,500	1,500
0.3	5,700	1,900
0.4	6,900	2,300
0.5	7,800	2,600

To obtain true penetration loads from the test data, the stress-deformation curve should be drawn and the zero point adjusted to eliminate the effect of surface irregularities. The value of CBR in percent is computed using the formula:

$$CBR = 100 \frac{L_t}{L_c} \text{ (in percent)}$$

in which:

CBR = Value of CBR in percent.

L_t = Test load in pounds to produce 0.1-inch penetration (from adjusted curve).

L_s = Value from table above of standard load in pounds at 0.1-inch penetration.

(15) The CBR usually selected for design is the relative bearing value in percent as obtained in step (14) above at 0.1-inch penetration. If the relative bearing value at 0.2-inch penetration is greater than that at 0.1-inch penetration, the test should be rerun. If check tests give similar results, the relative bearing value at 0.2-inch penetration should be taken as the CBR for design.

d. If compaction and control of moisture during construction differ from that specified in c above, CBR tests should be made in accordance with c (10) to (15) above on specimens prepared to produce the density, moisture, and structural conditions that will occur in the prototype. If conditions are such that saturation will not occur below the pavement (par. 131c) tests should be made on unsoaked samples.

e. Undisturbed samples of cohesive or partially cohesive soils (not readily compacted under traffic) should be tested for design purposes whenever compaction or disturbance will not be produced during construction or when existing pavements are to be evaluated. A sample of undisturbed subgrade material for testing should be obtained by forcing into the ground a California test mold, fitted with a cuttingedge collar, and at the same time carefully trimming away the soil from around the outside of the cylinder to prevent disturbance. The ends of the sample should be trimmed and paraffined, if tests will not be conducted immediately. For the test, the paraffin should be removed and a perforated base plate should be clamped into position. After the testing surface is carefully prepared the procedure for the test should be as described in c(7) to (15) above.

12. FIELD DENSITY TESTS. Determination of density of samples taken during construction is necessary to control compaction in the field. During the first few hours of compaction of a subgrade or base course samples should be taken and tested for density, and the results should be compared with the densities obtained by the laboratory compaction test (see par. 10 of this app.). Comparison is made on the basis of dry weight per cubic foot. The wet weight per cubic foot of compacted soil in the field (U_{fw}) is determined by one of the methods given below. The moisture content of the field sample (P_f) is determined as in paragraph 6 of this appendix. Then the unit dry weight (U_{fd}) of the field sample is:

$$U_{fd} = \frac{100 \times U_{fw}}{100 + P_f} \text{ (in pounds per cubic foot)}$$

The percent compaction (density) of the field sample, as compared with maximum density in the laboratory compaction test (par. 10 of this app. and fig. 283), is:

$$\text{Percent compaction (density)} = \frac{100 \times U_{fd}}{\text{Max } U_d}$$

If sufficient compaction is not obtained, more passes or heavier equipment should be used. For example, the weight of a sheepsfoot roller can be increased by adding water, sand, or oil to the drums. After a satisfactory field-compaction procedure is established it is not necessary to check compacted soil density unless different soils are encountered. However, until optimum moisture content can be determined by feel and visual characteristics, moisture content determinations should be made to insure that soil contains the proper moisture for compaction. Several methods are used to determine density of soil in place, the one to be used depending upon the type of soil and the experience of sampling personnel. Acceptable methods are as follows:

a. Cylinder. The cylinder method may be used for uniform fine sands, silts, or clays which do not contain gravel particles. The equipment consists of a metal cylinder, 6 inches in diameter and 6 inches long, with a cutting edge. As the cylinder is pushed into the soil usually it is necessary to remove the soil from around the cylinder, to relieve restraint. After the cylinder is full the top surface is trimmed with a steel straightedge. A plate is placed on top of the cylinder and the cylinder is inverted. The other soil surface is trimmed so the volume of the soil equals the volume of the cylinder. The sample is placed in a clean container for weighing or for drying and weighing.

b. Oil. The oil method may be used in soils sufficiently impervious to prevent any seepage of the oil into the soil during the test. Any type oil, such as crankcase oil, may be used. Prior to sampling, weight per cubic foot of the oil and weight of oil in the container are determined. In the field the surface of the soil is smoothed and leveled for an area about 12 inches in diameter. In the center of the area a hole is dug by hand or with a 6-inch auger, taking special care to place all the soil in a clean container, to be dried and weighed later. After the hole is cleaned it is filled rapidly with the oil so the volume of the oil equals the volume of the soil removed. The volume may be computed from the weight of the oil used to fill the hole.

c. Sand. The sand method may be used in any type of soil. It is the same as the oil method described above, except clean sand is used. The sand is dried thoroughly in the laboratory and placed in covered containers. The weight per cubic foot of the sand is determined before using it to measure volume of removed soil. Usually the sand is poured through a funnel held at a constant height above the sand surface. Care must be taken to prevent the sand from absorbing moisture, a small amount of which will cause bulking of the sand.

d. Chunk. The chunk method may be used for soils sufficiently cohesive to form a chunk when removed. It consists of determining the volume of a chunk of soil in the laboratory by the immersion method. A chunk of soil is removed in the field and taken to the laboratory. If it is sufficiently dense and cohesive, the volume is obtained by first weighing it in the air and then weighing it when immersed in water or oil. For most soils it is necessary to coat the chunk with paraffin to prevent breaking or crumbling. The paraffin coat is applied with brushes in either the field or the laboratory. If the soil cannot be removed as a chunk a pedestal is formed which is paraffin-coated with brushes; or, paraffin is poured around the pedestal, using a cylinder as a mold. The volume of the paraffin sample is determined by the immersion method in the laboratory. After the volume is determined the paraffin is peeled from the sample, placed in a pan of hot water, and melted. As the water cools clean hard paraffin is formed at the surface. Volume of the paraffin is determined by its weight and specific gravity (about 0.9). The volume of the soil is equal to the volume of the paraffined sample minus the volume of the paraffin. The weight of the soil sample is determined after drying in an oven.

e. Water. The water method is similar to the oil method except a rubber membrane is used in the hole to prevent seepage into surrounding soil. It may be used in all types of soil. The volume of soil removed equals the combined volume of rubber membrane and water. The unit dry weight of the soil in place can be determined by one of the above methods. If the soil is protected against loss of moisture until weighed, unit wet weight and moisture content can be determined. However, more satisfactory results usually can be obtained by determining moisture content on a separate sample. For gravelly soils it is necessary to obtain unit dry weight only of material passing the ¼-inch sieve so results can be compared with those obtained by the laboratory compaction method (par. 10 above). Unit weight of material passing the ¼-inch sieve can be computed by reducing the total dry weight and volume of the sample by the weight and volume of stones greater than ¼ inch. Volume of the stones can be determined by the immersion method.

13. EARTH SHRINKAGE. The earth shrinkage from excavation to embankment is equal to the percentage by which volume of excavation exceeds the volume of embankment. It is calculated from the equation:

$$S = 100 \frac{\text{fill } U_{fd} - \text{cut } U_{fd}}{\text{cut } U_{fd}} \text{ (in percent)}$$

Where:

Fill U_{fd} = unit dry weight of embankment, determined as in paragraph 12 of this appendix.

Cut U_{fd} = unit dry weight of excavation, determined as in paragraph 12 of this appendix.

S = shrinkage in percent.

14. PROPORTIONING AND TESTING SOIL AND AGGREGATE MIXTURES. **a.** Mixtures often are used in constructing subgrades and base courses. Table XLV lists tests generally used for investigating aggregates and mixtures for planning and design, and control tests employed during construction. Unless otherwise explained, procedures are those given in paragraphs 5 through 12 of this appendix.

b. When it is necessary to blend two or more materials, as in stabilizing clay subgrade with sand or in proportioning materials for a stabilized soil base, the procedure usually is one of preparing trial mixtures of representative samples of the available materials and testing the combinations to confirm their suitability. Proportions to be used in preparing trial mixes are estimated by comparing characteristics of the individual materials. For example, if a coarse and fine gravel are to be combined to produce a graded-

Table XLV. Tests.

Description	Investigation tests for planning and design	Control tests during construction
Stabilized subgrade (par. 128).	Compaction (optimum moisture, maximum density) and bearing-ratio tests on various combinations of subgrade soil and natural material to be admixed.	Gradation to check proportions. Field density to control compaction. Bearing ratio to confirm design.
Natural base course materials (par. 101a).	Liquid limit and plasticity index on fraction passing No. 40 sieve. Compaction (optimum moisture, and maximum density). Bearing ratio. Lay a trial section and test it under truck traffic.	
Processed base-course materials (par. 101b).	Combine various available materials by trial until a satisfactory mixture is obtained as shown by— Gradation test. Liquid limit and plasticity index on fraction passing No. 40 sieve. Compaction (optimum moisture and maximum density). Bearing ratio. Lay a trial section and test it under traffic.	Gradation. Liquid limit and plasticity index on fraction passing No. 40 sieve. Field density to control compaction. Bearing ratio to confirm design.
Bituminous mixtures (par. 103).	Sieve analysis of available aggregates to determine acceptability or need for blending or combination of additional natural material. After proper grading is achieved the combined aggregate is tested for liquid limit and plasticity index of fraction passing No. 40 sieve. Prepare trial mixtures using selected or available bitumen in proportion needed. Compact mixture in a cylinder and observe density and general character. Allow cylinder to cure in air for further observation. Lay trial section of mixture and test it under truck traffic.	Sieve analysis of aggregate in windrows after dry-mixing. Estimate required proportion of bitumen as per figure 35. Measure windrows, table LXXII. Compute quantity and length of spread of bitumen as per table LVIII.

gravel base material, an indication of the proper proportions for trial is obtained by studying the gradation curves of each material and estimating the percentage of each necessary to give a combined material having the gradation desired. Similarly, if a sandy soil is to be added to a clay soil, an indication of desirable proportions may be obtained from the plasticity indexes of the two. Adding a sandy soil with low PI to a clay with high PI produces a combination with an intermediate PI. The decrease in PI is approximately proportional to the amount of sandy soil added. Trial mixes then are tested for general suitability by appropriate procedures such as compaction and bearing ratio.

15. TESTING CONCRETE AND CONCRETE MATERIALS. a. Fine aggregate (sand). (1) Fine aggregate is judged by visual inspection for quality of individual particles. It is tested by sieve analysis for gradation and by washing for cleanliness. The washing test is made as follows: Fill a pint jar with sand to a depth of 4 inches and then almost fill with water. Shake for several minutes. If there is more than 1/4 inch of sediment on top of the sand after settling, the sand is unsuitable for important work. It may be made suitable by field-washing to remove excess dirt.
(2) Sand is also tested for presence of injurious organic matter as follows: Half-fill a bottle with sand to be tested. To it add a 3-percent solution of sodium hydroxide until the volume of sand and water after shaking amounts to 1 1/2 times the original volume of sand alone. Shake thoroughly and allow to stand for 24 hours. If the liquid above the sand is colorless or yellow, the sand is satisfactory as regards organic matter. The sand is questionable if medium brown and, if dark brown, it is unsuitable for important work unless strength tests prove the color-producing organic matter to be harmless. Field-washing to remove dirt usually removes considerable organic matter also.

b. Coarse aggregate. Coarse aggregate is judged by visual inspection and a sieve analysis. If it is dirty but otherwise satisfactory, field-washing is required.

c. Proportions. Proper proportions of water, cement, sand, and gravel are determined by trial mixes. The ratio of water to cement is held constant, while proportions of fine and coarse aggregate are varied until a mix is obtained having the required cement content per cubic yard and proper workability as judged by the slump test. (See table LXXV.)

d. Slump test. A conical shell of 16-gauge galvanized metal, with a base 8 inches and a top 4 inches in diameter, and 12 inches high, is filled to overflowing with concrete rodded into the shell in three separate layers, each layer receiving 25 strokes of a 5/8-inch bullet-pointed rod 24 inches long. The excess is struck off and the mold is lifted at once slowly and vertically. The amount of drop of the top of the mass below the original 12-inch height, measured in inches, is called the slump of the mix. The slump test is a convenient method of controlling and checking uniformity of concrete production. ·Any major change of aggregate gradation, moisture content, or proportions during operations will be evidenced by a change in slump. When this occurs it is a signal to check and adjust operations.

16. DIFFERENTIATION OF FINE-GRAINED SOILS BY LIQUID LIMIT AND PLASTICITY INDEX VALUES. a. For all plastic soils determination of grain-size distribution is of limited usefulness. For such soils the most important classification tests are liquid and plastic limit tests. These tests are best interpreted by plotting the liquid limit against the plasticity index (fig. 284). Plasticity index is defined as difference between the liquid and plastic limits. Typical inorganic clay generally will lie above the inclined line *A*. A liquid limit of 50, line *B*, is assumed as the dividing line between clays of relatively low compressibility (CL), and clays having high compressibility (CH). Silty and fine sandy soils having some plasticity (ML) and organic silts (OL) generally will lie below line *A* and to the left of line *B*. Organic clays (OH) and micaceous or diatomaceous silty soils (MH) also will plot below line *A*, but to the right of line *B*.

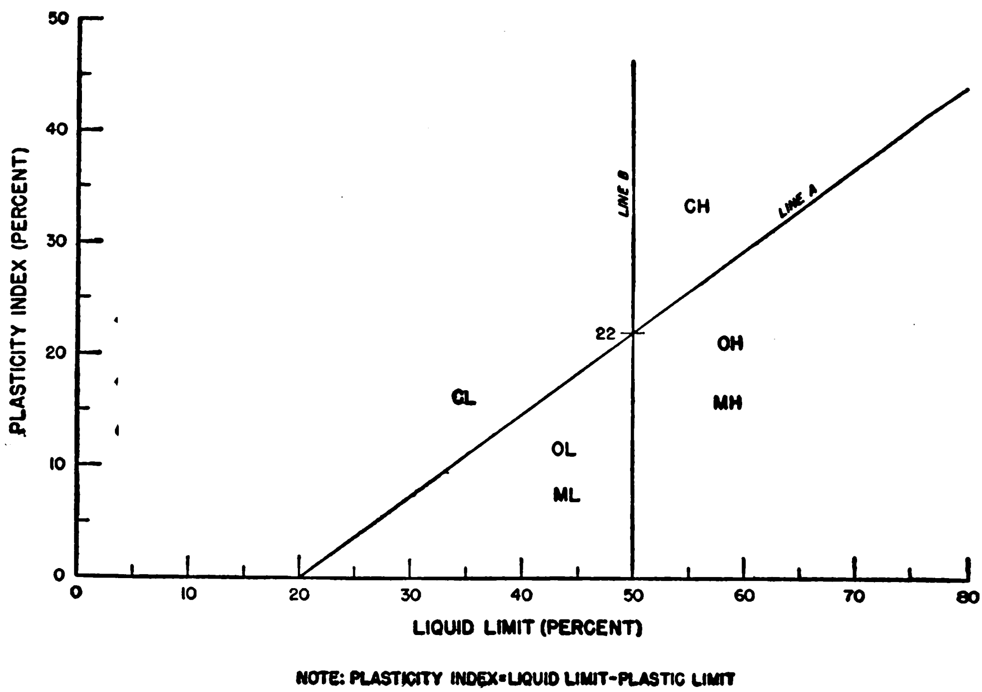


Figure 284. Soil identification by LL and PI tests.

b. The limits of inorganic silty soils (ML, MH) and organic silty and clay soils (OL, OH), when plotted on figure 283, overlap to such an extent that no line of demarcation can be drawn. However, visual and manual inspection generally is sufficient to distinguish between organic and inorganic soils. Also, limits of an organic soil as determined from an oven-dry sample are much

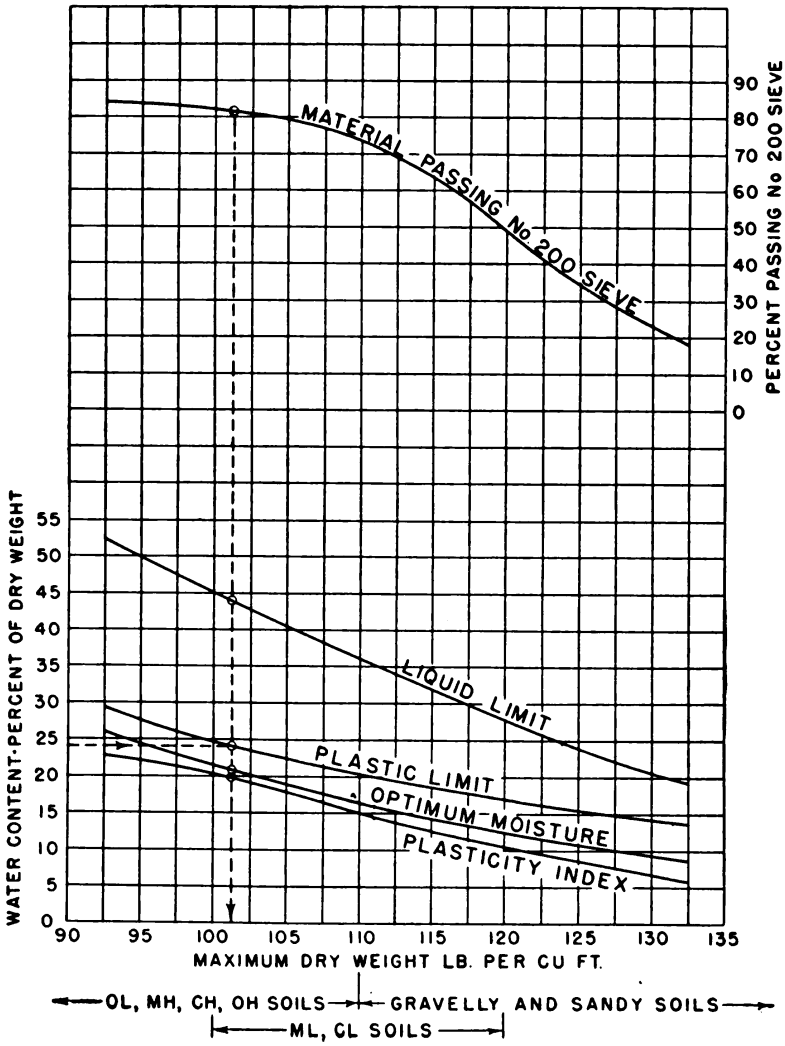


Figure 285. Average soil test values.

smaller than limits of the same soil as determined from a sample in its natural state of moisture; whereas, oven-drying of an inorganic soil will result in only minor changes in limit values.

17. CHARACTERISTICS OF AVERAGE SOILS. The results of tests on several thousand samples of soil used in compacted embankment constructions indicate a close relationship between maximum weight per cubic foot for any given soil and the liquid limit, plastic limit, plasticity index, and optimum moisture content. Figure 285 shows these relationships for 1,383 individual tests. The curves may be considered as representing average relationships among test results on typical soils. They may be used to aid in soil classification and to hasten field control-testing. For example, the plastic limit of a soil, which is easily and quickly determined, is found to be 24 percent. The chart is entered from the left on a horizontal line, representing 24 percent to an intersection with the plastic limit curve. A vertical line is drawn through this intersection to cross all other curves in the chart. Other values then are read as follows: material passing No. 200 sieve, 82 percent; liquid limit, 44 percent; optimum moisture, 21 percent; plasticity index, 20 percent; maximum dry weight, 101 pounds per cubic foot. These are average values, not exact for the particular soil in question, but they may be used for preliminary purposes until confirmed by actual test. Similarly, if any other test value is known for a particular soil, preliminary values of the others may be read from the chart

18. FIELD-LABORATORY TESTING EQUIPMENT. Following is a list of items included in the battalion laboratory set No. 1 issued to engineer aviation battalions. (See fig. 212.) Additional testing equipment is in depot stock primarily for use with heavy construction equipment or for other special purposes.

Quantity	Unit	Description
2	Each	Auger, posthole, 6-inch diameter.
20	do.	Bags, 10- x 18-inch, with drawstrings.
5	do.	Bags, 17- x 32-inch, with drawstrings.
1	do.	Balance, torsion, 4½-kg. capacity.
1	do.	Balance, triple-beam, with extra weight, 0.01 gram to 201 grams.
12	do.	Blades, hacksaw, hand, 10-inch, 18 teeth per inch.
2	do.	Book, note, level.
12	do.	Box, tin, seamless, round, low-form, flat-bottom, 4-oz. capacity.
12	do.	Box, tin, seamless, round, low-form, flat-bottom, 8-oz. capacity.
2	do.	Brush, paint, 1-inch wide.
2	do.	Brush, paint, 2-inch wide.
5	do.	Basket, iron, galvanized, 14-qt.
1	do.	California bearing ratio test equipment, complete.
1	do.	Chisel, woodworker's, ¾-inch.
1	do.	Compaction equipment, complete with tamper and tamper guide.
2	do.	Cylinder, glass, graduated, 100-cc.
1	do.	Duck, cotton, 60- x 60-inch.
1	do.	File, half-round, 12-inch.
1	do.	File, mill, 12-inch.
1	do.	Filler, battery, 6-oz., 10¾-inch long.
6	do.	Handle extensions, auger, posthole.
3	do.	Indicator, dial, 1-inch range.
2	do.	Knife, butcher, 6-inch blade.
5	Boxes	Label, paper, gummed.
1	Each	Liquid limit testing equipment complete with brass cup and Casagrenda type grooving tool.
3	do.	Molds, cylinder, 2-inch diameter, 4-inch high.
1	do.	Opener, can.
1	do.	Oven.
12	do.	Pad, memorandum, white, 5- x 8-inch.
24	do.	Pan, enamel, flat-bottom, 9-inch diam., 4-inch high.
100	Sheets	Paper, cross-section, 8½- x 11-inch, 10 x 10 sections to the inch.
50	do.	Paper, logarithmic, 8½- x 11-inch, 3 cycles x 10 to the inch.
25	Pounds	Paraffin, wax, in one-pound cakes.
6	Each	Pencil, china-marking, black.
12	do.	Pencil, lead, No. 3 with eraser.
1	Pair	Pliers, long-nose, side-cutting, 6-inch.

Quantity	Unit	Description
1	Each	Rule, steel, 12-inch with graduations in 16ths, 32nds, 65ths, and 100ths.
2	do.	Rule, tape, steel, 72-inch.
1	do.	Scale, spring-balance, 40-pound capacity.
1	do.	Scale, spring-balance, 60-pound capacity.
1	do.	Screwdriver, 4-inch long, ¼-inch blade.
1	do.	Screwdriver, 8-inch long, ⅜-inch blade.
1	do.	Sieve set, 8-inch diameter, half-height, consisting of— 1 each pan. 1 each cover. 1 each sieve, 1-inch. 1 each sieve, ¾-inch. 1 each sieve ¼-inch. 1 each sieve No. 4. 1 each sieve No. 10. 2 each sieve No. 40. 1 each sieve No. 60. 2 each sieve No. 100. 2 each sieve No. 200.
1	do.	Sieve set, portable type with interchangeable screens consisting of: 1 pair rockers. 1 each frame, 15¼ x 12¼ x 7¾ inches. 1 each screen, 2-inch opening. 1 each screen, 1½-inch opening. 1 each screen, ¾-inch opening. 1 each screen, ¼-inch opening. 1 each rocker pan.
2	do.	Spatula, steel-blade, 4-inch, ½-inch wide.
2	do.	Spoon, steel-tinned, 14 inches long.
2	do.	Stoves, gasoline, with windshield.
1	do.	Straightedge, steel, one beveled edge, 12-inch.
100	do.	Tag, shipping, 2⅜- x 4¾-inch.
1	do.	Thermometer, circular-dial, 8-inch steel stem, 50° to 300° F.
12	do.	Towel, cotton, 17- x 36-inch.
2	do.	Trowel, pointing, 2¼- x 4¾-inch blade.
1	Ball	Twine.
1	Each	Watch, stop.
1	Set	Weight, balance, 5 to 2,000 grams.
1	Each	Wrench, crescent-type, 1⅛-inch opening, 10 inches long.
4	do.	Wrench, pipe, Stillson type, ¼- to 1-inch opening, 10 inches long.
1	do.	Chest, bearing-ratio-equipment.
1	do.	Chest, soils, sampling-equipment.
1	do.	Chest, soils, testing-equipment.

APPENDIX IV LOGISTICS

Table XLVI. Logistical data for aviation engineer units.[1]

Unit	Table of Equipment		30 days maintenance[2]			Engineer, Table of Equipment	
	Ship tons[3]	Long tons[4]	Ship tons	Long tons	Tanker gallons[5]	Ship tons	Long tons
Topography company	1,000	130	130	50	5,200	310	40
Engineer aviation battalion	5,300	1,200	740	320	52,500	2,240	650
Airborne battalion	1,200	210	330	170	8,300	320	80
Camouflage battalion	1,800	300	330	180	20,000	87	30
Fire fighting platoon	140	30	24	10	1,000	60	10
Utilities detachment	1,100	200	130	40	14,000	670	130
Regiment less 3 battalions	3,100	760	400	160	17,600	1,860	530
Air force headquarters company	1,100	180	160	70	9,400	400	80
Depot company	600	110	130	60	8,900	200	60

1 No class IV items included in any figures.
2 Includes food, clothing, heating fuel, and all class II spare parts and replacements.
3 Ship ton is a volume measurement equal to 40 cubic feet.
4 Long ton is a weight measurement equal to 2,240 pounds.
5 Includes gasoline, Diesel, and lubricating oils. One aviation engineer battalion uses per 20-hour day:
1,250 gal. gasoline.
500 gal. Diesel oil No. 2.
80 gal. lubricating oil.
700 lb. lubricating grease.

Table XLVII. Loading capacities of cargo airplanes and gliders.

Type	Design gross weight (pounds)	Payload or cargo for round trip*		Cruising Speed (miles per hour)	Take-off distance over 50-foot obstacle (foot)	Loading method	Location
		500 miles	1,200 miles				
C-46A	48, 000	11, 000	9, 500	195	3, 500	Ramp	High, medium wide, left side door.
C-47A	29, 000	7, 000	5, 000	170	2, 500	Ramp	Medium low, medium wide, left side door.
C-49	29, 000	7, 000	5, 000	170	2, 500	Step	Medium low, small left side door.
C-53	29, 000	7, 000	5, 000	170	2, 500	Step	Medium low, small left side door
C-54A	65, 000	12, 000	12, 000	225	2, 925		High, medium wide, left side door.
C-76	33, 000	3, 260	3, 200	146	1, 725		Low, wide, rear-end door.
CG-4A	6, 800	3, 750		120-140	800-1, 200	Nose Ramp	Low, wide, front-end door.

* Cargo carried only on outgoing trip includes fuel.

Table XLVIII. Water—average requirements (gallons) per unit per day.[1, 5]

	In battle	March and bivouac	Temporary camp	Semi-permanent camp in rest area	Cantonment
Men	½–2[2, 3, 4]	2	5	30	50
Animals	3–5	10	10	30	50
Motor vehicles	¼–1[3]	¼–1	¼–1	¼–30	¼–50

[1] Modify according to circumstances, especially in hot climates. Maximum requirements may exceed the average by 15 to 100 percent.
[2] One half gallon per man and 3 gallons per animal is the absolute minimum for not more than 3 days.
[3] Recent operations in Libya indicate that 2½ gallons per man and 6 gallons per radiator per day should be provided in similar climates.
[4] Recent operations in the south-west Pacific indicate that 20 gallons per man per day is sufficient in operational semipermanent camps.
[5] Approximate weight of fresh water:

Pounds per gallon	*Pounds per cubic foot*	*Pounds per barrel (42 gallons)*
8.4	62.4	350.5

Table XLIX. Gasoline requirements for an airborne engineer aviation battalion per day.[1]

Equipment	Number per battalion	Gallons gasoline per hour per piece equipment	Hours in operation per day	Gallons gasoline
Tractor, crawler	19	2.00	22	836.0
Tractor, rubber-tired	13	1.71	22	488.8
Truck, ¼-ton, w/load	6	[2] 1.33	8	63.6
Truck, ¼-ton, no load	17	[3] 14 miles/gal.	50 miles/24 hr.	61.2
Electric lighting set	6	1.00	10	60.0
Water-purification unit	1	0.25	8	2.0
Lantern, gas mantle	28	0.01	10	3.0
Welder, arc	1	2.00	2	4.0
Asphalt kettle (one-burner)	3	4.00	2	24.0
Saw, chain	3	0.75	4	9.0
Compressor, air	8	1.00	3	24.0

Total gasoline = 1,575 gallons, (battalion) 24 hours.

[1] Gasoline consumption measured under working conditions of less than one day.
[2] Used as tractor in low-low range.
[3] Gallons per hour not available.

Table L. Gasoline and oil.

	Container	Contents (gallons)	Cubic feet	Weight (pounds)
Gasoline	Standard container	5	1.0	40
Gasoline	Drum (small)	10	3.0	80
Gasoline	Commercial drum (capacity 55-gallons)	50	9.5	400
Oil	Container, 2-gallons	2	0.3	15
Oil	Commercial drum	55	9.5	450

Approximate weight

	Pounds per gallon	Pounds per cubic foot	Pounds per barrel*
Gasoline	6.1	45.6	256.2
Oil, lubricant	7.0	52.4	294.0

* One barrel equals 42 U. S. gallons.

Table LI. Ammunition, small-arms.

Caliber	Item	Container		Unit of fire (rounds per weapon)	Weight unit of fire per weapon (pounds)
		Rounds	Gross weight (pounds)		
.30	Carbine, M–1	2,700	91	60	2.02
.30	Automatic rifle	1,500	110	750	55.00
.30	Machine gun, L and H (MG belt)	1,250	101	2,000	161.30
.30	Rifle (ball, 8 per clip)	1,200	101	150	12.63
.45	Pistol	2,000	110	10	0.55
.45	Submachine gun	2,000	110	200	11.00
.50	Machine gun, AA, WC	265	96	1,200	434.71
.50	Machine gun, HB, Flex	265	96	500	181.00

Table LII. Weights and cubages of rations.

Item	Unit	Weight (pounds)	Remarks
A-ration	Each	5.12 net 6.22 packed Average for planning, 6 per ration	Perishable—contains fresh food.
B-ration	Each	Same as A-ration	Same as A-ration with nonperishables. Cubage (each) average: 0.1462 cubic feet.
C-ration, unpacked Package of 8	Each Package	4.2 41	Prepared meals in individual cans, 6 cans per ration. Cubage-package: 1.1007 cubic feet.
D-ration, unpacked Package of 48	Each Package	.75 51	3 chocolate bars per ration. Cubage-package: 1.0539 cubic feet.
K-ration, unpacked Package of 12	Each Package	2.3 43	Nonperishable, concentrated meals in individual packages, 3 packages per ration. Cubage-package: 1.3754 cubic feet.
Ten and one	Each	45	Cubage estimated, 2.3 cubic feet.

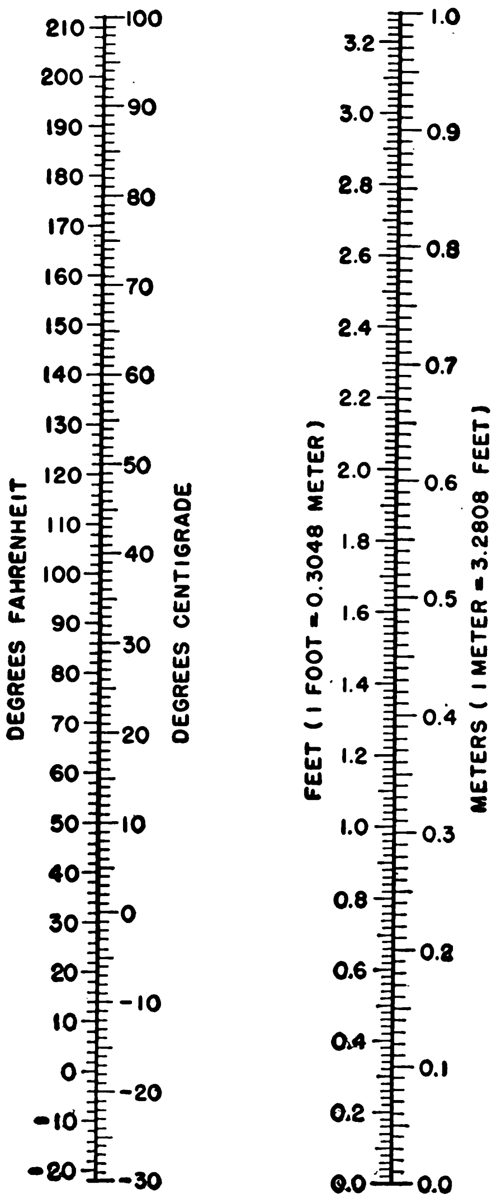
APPENDIX V
REFERENCE DATA

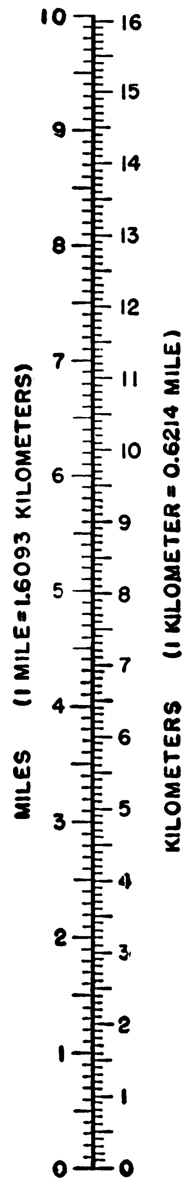
Table LIII. Factors for conversion of units.
(To convert A to B, multiply A by C. To convert B to A, multiply B by D)

Unit A	Factor C	Factor D	Unit B
Length:			
Miles	*63,360.0	0.00001578	Inches.
Do	*5,280.0	.0001894	Feet.
Do	1.609	.6214	Kilometers.
Meters	3.281	.3048	Feet.
Kilometers	3,281.0	.0003048	Do.
Inches	2.540	.3937	Centimeters.
Surface:			
Square miles	*27,878,400.0	.00000003587	Square feet.
Do	*640.0	.001563	Acres.
Do	2.59	.3861	Square kilometers.
Acres	*43,560.0	.00002296	Square feet.
Do	4,046.9	.0002471	Square meters.
Hectares	2.471	.4047	Acres.
Do	*10,000.0	*.0001	Square meters.
Square inches	6.452	.1550	Square centimeters.
Square meters	10.76	.09290	Square feet.
Volume:			
Cubic feet	*1,728.0	.0005787	Cubic inches.
Cubic inches	16.39	.06102	Cubic centimeters.
Cubic meters	35.31	.2832	Cubic feet.
Cubic feet	7.481	.1337	U. S. gallons
Do	6.229	.1605	Imperial gallons
Do	28.32	.03531	Liters.
U. S. gallons	*231.0	0.004329	Cubic inches.
Do	3.785	.2642	Liters.
Imperial gallons	1.200	.8331	U. S. gallons.
U. S. bushels	1.244	.8036	Cubic feet.
Fluid ounces	1.805	.5541	Cubic inches.
Acre-feet	*43,560.0	.00002296	Cubic feet.
Millions, U. S. gal	133,700.0	.000007481	Do.
Flowing water:			
Second-feet	*60.0	.01667	Cubic feet per minute.
Do	448.8	.002228	U. S. gallons per minute.
Do	1.984	.5042	Acre-feet per 24 hours.
Cubic feet per minute	7.481	.1337	U. S. gallons per minute.
Velocities:			
Miles per hour	1.467	.6818	Feet per second.
Meters per second	3.281	.3048	Do.
Do	2.237	.4470	Miles per hour.
Pressure:			
Atmospheres (mean)	33.90	.02950	Feet of water.
	14.70	.0680	Pounds per square inch.
	29.92	.03342	Inches of mercury.
Pounds per square inch	2.036	.4912	Do.
Feet of water	62.42	.01602	Pounds per square foot.
Weight:			
Pounds	*7,000.0	.0001429	Grains.
Kilograms	2.205	.4536	Pounds.
Long tons	*1.120	.8929	Short tons.
Power:			
Horsepower	*550.0	.001818	Foot-pounds per second.
Kilowatts	1.341	.746	Horsepower.

* Exact values.

Table LIV. Conversion charts.




MILES (1 MILE = 1.6093 KILOMETERS)
KILOMETERS (1 KILOMETER = 0.6214 MILE)

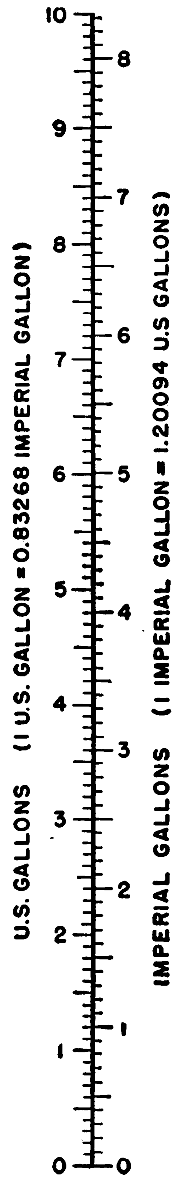

U.S. GALLONS (1 U.S. GALLON = 0.83268 IMPERIAL GALLON)
IMPERIAL GALLONS (1 IMPERIAL GALLON = 1.20094 U.S GALLONS)

*Table LV. Useful formulas.**

Areas
(1) Circle: $A = \pi r^2 = \frac{\pi d^2}{4}$
(2) Triangle. $A = \frac{1}{2} bh$
(3) Trapezoid (one pair of opposite sides parallel): $A = \frac{1}{2} h (b + c)$
(4) Ellipse: $A = \pi l f$
(5) Sphere: $A = 4 \pi r^2$

Volumes
(1) Prism or cylinder: $V = A_b h$
(2) Pyramid or cone: $V = \frac{1}{3} A_b h$
(3) Frustrum of pyramid or cone: $V = \frac{1}{3} (A_1 + A_2 + \sqrt{A_1 + A_2}) h$
(4) Sphere: $V = \frac{4}{3} \pi r^3$

* Meaning of symbols:

r = radius
d = diameter
b = base
h = altitude
b and c = parallel sides
l and f = semiaxes
π = 3.1416
A_b = area of base
A_1 and A_2 = areas of bases

Table LVI. Weights of common materials.

Material	Weight per cubic foot (pounds)
Aluminum:	
Cast	160
Wire	168
Asphalt	69–94
Brass	510–542
Brick	110–130
Bronze	545–555
Coal:	
Anthracite	97
Bituminous	84
Concrete:	
Reinforced	150
Plain	140–150
Copper, cast	549–558
Earth:	
Clay:	
Dry, compacted	100
Damp, plastic	110
Common:	
Dry, loose	65–88
Moist, compacted	100
Mud, wet:	
Fluid	104–120
Compacted	110–130
Sand:	
Dry, compacted	110
Damp, loose	94
Gravel, crushed rock:	
Damp, loose	82–125
Dry, compacted	90–145
Ice	56
Iron:	
Gray cast	439–445
Wrought	487–492
Lead	710

Material	Weight per cubic foot (pounds)
Lime	53–75
Masonry:	
Mortar rubble	155
Dry rubble	125
Rock, solid:	
Granite	125–187
Shale	162
Soapstone	162–175
Trap	187–190
Salt	129–131
Snow:	
Fresh fallen	5–12
Wet, compact	15–20
Steel	474–494
Tar	75
Tin	455
Water:	
Fresh	62.4
Sea	64.0
Zinc	438

Petroleum products	Pounds per gallon
Asphaltic cement	8.45
Liquid asphalt	8.30
Gasoline	5.62–6.10
Oil, lubricating	6.694–7.50

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Table LVII. Average weights and volumes of bituminous materials.

	Gallons per ton at 60° F.	*Barrels per ton at 60° F.	Pounds per gallon at 60° F.	Pounds per barrel* at 60° F.
SC, MC, AND RC ASPHALTS				
Grade:				
0	257	6.11	7.79	327
1	251	5.98	7.97	335
2	248	5.90	8.07	339
3	245	5.84	8.16	343
4	243	5.78	8.23	346
5	241	5.74	8.30	349
6 (SC only)	239	5.70	8.36	351
ASPHALT CEMENTS				
Penetration:				
40 to 100	235	5.60	8.51	358
100 to 200	237	5.64	8.44	354
EMULSIFIED ASPHALTS				
All grades	240	5.72	8.33	350
TARS				
RT-1	211	5.01	9.50	399
RT-2	209	4.97	9.56	402
RT-3	208	4.94	9.64	404
RT-4	206	4.90	9.71	408
RT-5	205	4.87	9.78	411
RT-6	203	4.84	9.85	414
RT-7	201	4.80	9.93	417
RT-8	200	4.76	10.00	420
RT-9	199	4.73	10.07	423
RT-10	197	4.70	10.15	426
RT-11	195	4.66	10.22	430
RT-12	194	4.63	10.30	432
RTCB-5	205	4.87	9.78	411
RTCB-6	203	4.84	9.85	414

* A barrel is 42 U. S. gallons. This is a common unit of measure in United States. Steel drums in which bituminous products are shipped usually contain 55 U. S. gallons.

Table LVIII. Distribution table for bituminous materials.
(1.0 gallon spread per square yard of finished surface)

Gallons of bitumen	Width of spread in feet												Gallons of bitumen
	1	2	3	4	5	6	7	8	9	10	11	12	
	Length of spread in linear feet												
5	45	23	15	11	9	8	6	6	5	5	4	4	5
10	90	45	30	23	18	15	13	11	10	9	8	7	10
15	135	68	45	34	27	23	19	17	15	14	12	11	15
20	180	90	60	45	36	30	26	22	20	18	16	15	20
25	225	113	75	56	45	38	32	28	25	23	21	19	25
30	270	135	90	68	54	45	38	34	30	27	25	23	30
35	315	158	105	79	63	53	45	39	35	31	29	26	35
40	360	180	120	90	72	60	51	45	40	36	33	30	40
45	405	203	135	101	81	68	58	50	45	40	37	34	45
50	450	225	150	113	90	75	64	56	50	45	41	38	50
55	495	248	165	124	99	83	70	62	55	50	45	41	55
60	540	270	180	135	108	90	77	67	60	54	49	45	60
65	585	293	195	146	117	98	83	73	65	59	53	49	65
70	630	315	210	158	126	105	90	79	70	63	57	53	70
75	675	338	225	169	135	113	96	84	75	68	62	56	75
80	720	360	240	180	144	120	102	90	80	72	66	60	80
85	765	383	255	191	153	127	109	95	85	77	70	64	85
90	810	405	270	203	162	135	115	101	90	81	74	68	90
95	855	428	285	214	171	143	122	107	95	85	78	71	95
100	900	450	300	225	180	150	128	112	100	90	82	75	100

Table LVIII. Distribution table for bituminous materials.—Continued.

Gallons of bitumen	Width of spread in feet												Gallons of bitumen
	1	2	3	4	5	6	7	8	9	10	11	12	
	Length of spread in linear feet												
200	1, 800	900	600	450	360	300	256	225	200	180	164	150	200
300	2, 700	1, 350	900	675	540	450	386	338	300	270	246	225	300
400	3, 600	1, 800	1, 200	900	720	600	514	450	400	360	327	300	400
500	4, 500	2, 250	1, 500	1, 125	900	750	643	563	500	450	409	375	500
600	5, 400	2, 700	1, 800	1, 350	1, 080	900	772	675	600	540	491	450	600
700	6, 300	3, 150	2, 100	1, 575	1, 260	1, 050	900	788	700	630	573	525	700
800	7, 200	3, 600	2, 400	1, 800	1, 440	1, 200	1, 029	900	800	720	655	600	800
900	8, 100	4, 050	2, 700	2, 025	1, 620	1, 350	1, 157	1, 013	900	810	736	675	900
1, 000	9, 000	4, 500	3, 000	2, 250	1, 800	1, 500	1, 286	1, 125	1, 000	900	818	750	1, 000
1, 100	9, 900	4, 950	3, 300	2, 475	1, 980	1, 650	1, 415	1, 237	1, 100	990	900	825	1, 100
1, 200	10, 800	5, 400	3, 600	2, 700	2, 160	1, 800	1, 543	1, 350	1, 200	1, 080	982	900	1, 200
1, 300	11, 700	5, 850	3, 900	2, 925	2, 340	1, 950	1, 671	1, 462	1, 300	1, 170	1, 064	975	1, 300
1, 400	12, 600	6, 300	4, 200	3, 150	2, 520	2, 100	1, 800	1, 575	1, 400	1, 260	1, 146	1, 050	1, 400
1, 500	13, 500	•6, 750	4, 500	3, 375	2, 700	2, 250	1, 929	1, 688	1, 500	1, 350	1, 228	1, 125	1, 500

Controlling rate of application of bitumen. *a.* When distribution of bituminous material is specified in terms of gallons per square yard as in surface treatment, seal coat, and penetration construction, table LVIII is used to determine the distance to be covered by a distributor load. For example, to spread a distributor load of 1,250 gallons at 0.25 gallon per square yard over a width of 10 feet, the length of spread, from table LVIII, is (1,080 + 45) = 1,125 feet, at the rate of 1.0 gallon per square yard. At 0.25 gallon per square yard the length of spread is $\frac{1.125}{0.25} = 4{,}500$ feet. The bitumeter device on the distributor, operated by the cycle-type wheel shown in figure 109, is used to control the required spread. Table LX may be used for determining the quantity of bitumen in partly filled tank or distributor.

b. When bitumen distribution is specified in terms of percentage (p) by weight of aggregate, as in adding bitumen to aggregate to be mixed in place, first it is necessary to find the cross-sectional area (A) of the windrow, as illustrated in table LXXII. Next, determine the dry loose unit weight (W_1) of a representative sample of the aggregate. To determine (W_1) use a box or pail having a volume from ½ to 1 cubic foot. Accurately determine its level full volume (V) by measurement or by liquid. Fill the container level full with a representative sample of the dry loose aggregate and weigh the contents (w). Loose unit weight of aggregate is:

$$W_1 = \frac{w}{V} \text{ (pounds per cubic foot).}$$

Compacted unit weight (Wc) will be about 1.25 times W_1. The weight of bitumen (Bw) to be added per linear foot of windrow then is:

$$Bw = p \times A \times W_1.$$

The volume of bitumen (Bv) per linear foot of windrow is obtained by dividing Bw by the weight per gallon of the bitumen (U) obtained from table LVII.

$$Bv = \frac{Bw}{U} = \frac{p \times A \times W_1}{U} \text{ (gallons of bitumen per linear foot of windrow).}$$

This quantity of bitumen generally is applied in two or more applications. If Bv works out to be 2.4 gallons per linear foot, the spreading could be made in three applications of 0.8 gallon each. A distributor load of 1,250 gallons would be uniformly spread over $\frac{1.250}{0.8} = 1{,}560$ linear feet of windrow, and three loads would be required to apply the total quantity required. The tachometer and bitumeter devices (fig. 109) on the distributor are used to control the desired spread.

Table LIX. Gallons of bitumen required per mile at various rates of application per square yard.

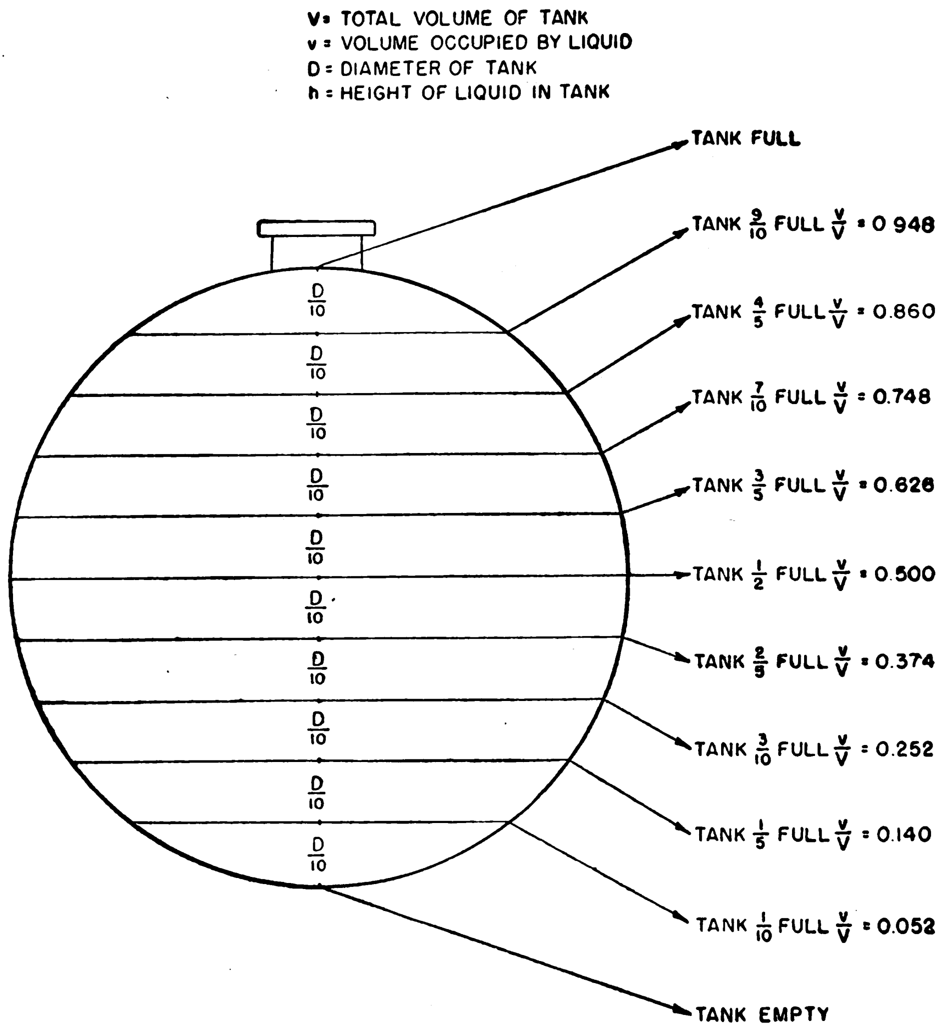
Width (feet)	1/8 gal.	1/5 gal.	1/4 gal.	1/3 gal.	4/10 gal.	1/2 gal.	3/4 gal.	1 gal.
18	1, 320	2, 112	2, 640	3, 520	4, 224	5, 280	7, 920	10, 560
17	1, 247	1, 995	2, 493	3, 324	3, 989	4, 987	7, 479	9, 971
16	1, 173	1, 877	2, 347	3, 129	3, 754	4, 693	7, 041	9, 387
15	1, 100	1, 760	2, 200	2, 933	3, 520	4, 400	6, 600	8, 800
14	1, 027	1, 643	2, 053	2, 738	3, 285	4, 107	6, 159	8, 213
13	953	1, 525	1, 907	2, 542	3, 050	3, 813	5, 721	7, 627
12	880	1, 408	1, 760	2, 346	2, 816	3, 520	5, 280	7, 040
11	807	1, 291	1, 613	2, 151	2, 581	3, 227	4, 839	6, 454
10	734	1, 173	1, 467	1, 955	2, 346	2, 933	4, 401	5, 867
9	660	1, 056	1, 320	1, 760	2, 112	2, 640	3, 960	5, 280

Table LX. Contents of cylindrical and elliptical tanks (horizontal).

(Full capacity in gallons = [.7854 x dia.² (inches) x length (inches)] ÷ 231)

Percent of depth		Percent of capacity		Percent of depth		Percent of capacity	
1—filled	2—unfilled	1a—filled	2a—unfilled	1—filled	2—unfilled	1a—filled	2a—unfilled
1	99	0.20	99.80	26	74	20.73	79.27
2	98	0.50	99.50	27	73	21.86	78.14
3	97	0.90	99.10	28	72	23.00	77.00
4	96	1.34	98.66	29	71	24.07	75.93
5	95	1.87	98.13	30	70	25.31	74.69
6	94	2.45	97.55	31	69	26.48	73.52
7	93	3.07	96.93	32	68	27.66	72.34
8	92	3.74	96.26	33	67	28.84	71.16
9	91	4.45	95.55	34	66	30.03	69.97
10	90	5.20	94.80	35	65	31.19	68.81
11	89	5.98	94.02	36	64	32.44	67.56
12	88	6.80	93.20	37	63	33.66	66.34
13	87	7.64	92.36	38	62	34.90	65.10
14	86	8.50	91.50	39	61	36.14	63.86
15	85	9.40	90.60	40	60	37.39	62.61
16	84	10.32	89.68	41	59	38.64	61.36
17	83	11.27	88.73	42	58	39.89	60.11
18	82	12.24	87.76	43	57	41.14	58.86
19	81	13.23	86.77	44	56	42.40	57.60
20	80	14.23	85.77	45	55	43.66	56.34
21	79	15.26	84.74	46	54	44.92	55.08
22	78	16.32	83.68	47	53	46.19	53.81
23	77	17.40	82.60	48	52	47.45	52.55
24	76	18.50	81.50	49	51	48.73	51.27
25	75	19.61	80.39	50	50	50.00	50.00

Columns No. 1 and No. 1a should be used together to ascertain percentage of capacity filled when less than 50 percent.
Columns No. 2 and No. 2a should be used together to ascertain percentage of capacity filled when greater than 50 percent.



TANK DIVIDED INTO 10 PARTS OF EQUAL HEIGHT. (CASE IN WHICH MEASUREMENT IS TAKEN WITH AN ORDINARY FOOT RULE.)

Table LXI. Temperature of saturated steam at various gauge pressures.

Gauge pressure (lb. per sq. in.)	Temperature of saturated steam (°F.)	Highest temperature a liquid can be heated in a vessel with heating equipment 85 percent efficient
50	297	253
55	302	257
60	307	261
65	312	265
70	316	269
75	320	272
80	324	275
85	327	278
90	331	281
95	334	284
100	338	287
105	341	290
110	344	292
115	347	295
120	350	298
125	353	300
130	355	302
135	358	304
140	361	307
145	363	309
150	366	311

Table LXII. U. S. standard sieve data.

Bureau of Standard-sieve number	Specified sieve opening		Specified wire diameter	
	Inches	Millimeters	Inches	Millimeters
4	.187	4.76	.050	1.27
5	.157	4.00	.044	1.12
6	.132	3.36	.040	1.02
7	.111	2.83	.036	.92
8	.0937	2.38	.0331	.84
10	.0787	2.00	.0299	.76
12	.0661	1.68	.0272	.69
14	.0555	1.41	.0240	.61
16	.0469	1.19	.0213	.54
18	.0394	1.00	.0189	.48
20	.0331	.84	.0165	.42
25	.0280	.71	.0146	.37
30	.0232	.59	.0130	.33
35	.0197	.50	.0114	.29
40	.0165	.42	.0098	.25
45	.0138	.35	.0087	.22
50	.0117	.297	.0074	.188
60	.0098	.250	.0064	.162
70	.0083	.210	.0055	.140
80	.0070	.177	.0047	.119
100	.0059	.149	.0040	.102
120	.0049	.125	.0034	.086
140	.0041	.105	.0029	.074
170	.0035	.088	.0025	.063
200	.0029	.074	.0021	.053
230	.0024	.062	.0018	.046
270	.0021	.053	.0016	.041
325	.0017	.044	.0014	.036

Table LXIII. Linear feet of spread of gravel or crushed rock to produce required thickness.

Width, feet	Thickness		Linear feet of spread, truckload 1 cubic yard.
	Inches	Condition*	
10	1	Loose	324
		Compacted	259

* Ratio of loose thickness to compacted thickness assumed to be 1.25.

Example: Length of spread for 2½-cubic-yard truckload of gravel to produce 4-inch compacted thickness, 18 feet wide, is:

$$L = 259 \times \frac{10}{18} \times \frac{1}{4} \times \frac{2.5}{1} = 90 \text{ feet.}$$

Table LXIV. Cubic yards, loose measure, gravel or crushed rock required per linear unit of road.

Width (feet)	Thickness		Length of road section		
	Inches	Condition*	100 feet	100 yards	1 mile
10	1	Loose	3.09	9.26	162.9
		Compacted	3.86	11.57	203.6

* Ratio of loose thickness to compacted thickness assumed to be 1:25.
Example: Quantity required for 4 inches compacted course on 350 yards of road, 18 feet wide, is:

$$Q = 11.57 \times \frac{18}{10} \times \frac{4}{1} \times \frac{350}{100} = 291.5 \text{ cubic yards, loose measure.}$$

Table LXV. Square yards per 100 feet, per 100 yards, and per mile, for various surface widths.

Width in feet	Number of square yards		
	Per 100 feet	Per 100 yards	Per mile
9	100.0	300.0	5,280
10	111.1	333.3	5,867
16	177.8	533.3	9,387
18	200.0	600.0	10,560
20	222.2	666.6	11,734

Table LXVI. Pounds of aggregate per square yard required for various thicknesses of compacted layers.

Weight of 1 cubic yard dry, loose aggregate (pounds)	Thickness of compacted layer					
	½ inch	¾ inch	1 inch	2 inches	2 ½ inches	3 inches
2, 100	37	56	74	149	186	223
2, 200	38	58	77	154	192	231
2, 300	40	60	80	159	199	239
2, 400	41	61	82	164	205	246
2, 500	42	63	84	169	211	253
2, 600	43	65	87	173	217	260
2, 700	44	67	89	178	222	267
2, 800	45	68	91	182	227	273
2, 900	47	70	93	186	233	279
3, 000	47	71	95	190	237	285

Table LXVII. Average weights of aggregate and soils per cubic yard.

Description	Loose (pounds)	Compacted (pounds)
Graded gravel or crushed rock	2, 800	3, 600
Course material without fines—macadam aggregate	2, 500	3, 100
Graded sand	2, 600	3, 300
Earth	2, 100	2, 700

Table LXVIII. Volumes of cuts and fills in cubic yards per 100 feet of length.[1]

Average depth of cut or height of fill (feet)	Side slope 1 to 1—width of base of cut or crown of fill (feet)[2]								Add for each additional 2 feet of width	Add where slope is 1½ to 1	Add where slope is 2 to 1
	14	16	18	20	22	24	26	28			
1	56	63	70	78	85	92	100	107	7	2	4
2	119	133	148	163	178	192	208	222	15	7	15
3	189	211	233	256	278	300	323	344	22	16	33
4	267	296	326	356	385	415	444	474	30	30	59
5	352	389	426	463	500	537	574	611	37	46	93
6	444	489	533	578	622	667	710	756	45	67	133
7	544	596	648	700	752	803	855	907	52	91	181
8	652	711	770	830	889	948	1,010	1,067	59	118	237
9	767	833	900	967	1,033	1,100	1,167	1,233	67	150	300
10	889	936	1,037	1,111	1,185	1,259	1,333	1,407	74	185	370
11	1,019	1,100	1,181	1,263	1,344	1,426	1,507	1,589	82	224	448
12	1,156	1,244	1,333	1,422	1,511	1,600	1,688	1,778	89	267	534
13	1,300	1,396	1,493	1,589	1,685	1,781	1,888	1,974	96	313	626
14	1,452	1,556	1,659	1,763	1,867	1,970	2,074	2,178	104	363	725
15	1,611	1,722	1,833	1,944	2,055	2,166	2,268	2,389	111	426	852
16	1,778	1,896	2,015	2,133	2,251	2,370	2,488	2,607	119	474	948
17	1,952	2,078	2,204	2,330	2,456	2,581	2,707	2,833	126	534	1,068
18	2,133	2,267	2,400	2,533	2,666	2,800	2,933	3,067	133	598	1,196
19	2,322	2,463	2,604	2,744	2,885	3,025	3,168	3,307	141	667	1,334
20	2,519	2,667	2,815	2,963	3,111	3,259	3,408	3,556	148	740	1,480
21	2,722	2,878	3,033	3,189	3,344	3,500	3,657	3,811	156	815	1,630
22	2,933	3,096	3,259	3,422	3,585	3,748	3,913	4,074	163	894	1,788

[1] For fills under 2 feet allow 20 percent for shrinkage; over 2 feet allow 15 percent.
[2] Width of roadbed on fills should be for 2 feet greater than in cuts.

Table LXIX. Earth-fill volumes.

a. For computing volumes of earthwork:

$$V = \frac{(A_1 + A_2)}{2} \times \frac{L}{27}$$

Where:

V = volume of cut or fill in cubic yards.
A_1 = area of cross section at one end in square feet.
A_2 = area of cross section at other end in square feet.
L = distance between end sections in feet.

b. For transportation of earth, gravel or crushed rock:

$$Q = \frac{60}{d + \frac{2h}{r}} \times C$$

Where:

Q = cubic yards, place measure, moved per hour.
h = length of haul in feet.
C = cubic yards moved per load.
r = rate of vehicle in feet per minute (normally about 200 for animal-drawn vehicles; 700 for trucks).
d = minutes during which vehicle is not in motion (loading, unloading, waiting).

c. Volume of conical crater:

$$V = \frac{\pi D^2 d}{12}$$

Where:

V = volume in cubic yards.
π = 3.1416 or $\frac{22}{7}$ approximately.
D = distance across crater in yards.
d = depth of crater in yards.

d. Prismoidal formula:

$$V = (A_o + 4A_n + A_1)\frac{L}{6} \times \frac{1}{27}$$

Where:

V = volume in cubic yards.
A_o and A_1 = areas in end planes in square feet.

A_m = area of middle section parallel to the end planes in square feet.

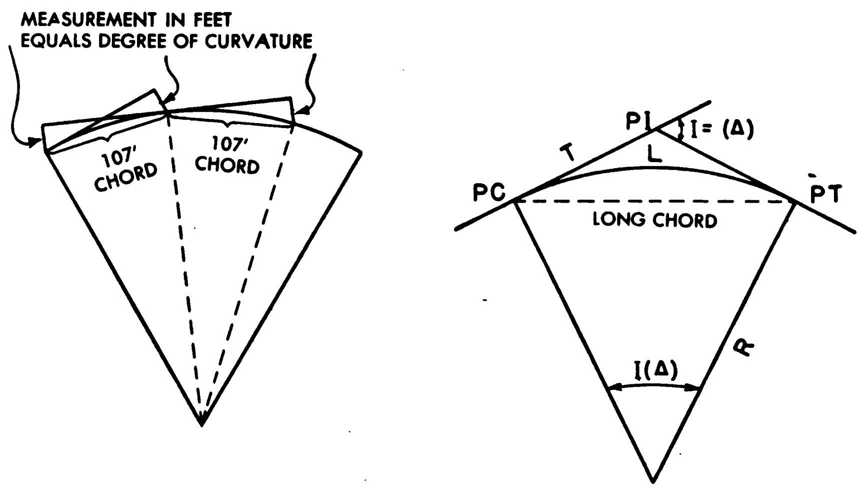
L = length of prismoid, or perpendicular distance between end planes in feet.

Table LXX. Data on earth-handling with hand tools.

Type of material	Cubic yards per man per hour					
	Excavation with pick and shovel to depth indicated				Loosening earth	Loading in trucks or wagons—1 man with shovel and loose soil
	0 to 3 feet	0 to 5 feet	0 to 8 feet	0 to 10 feet	Man with pick	
Sand	2.1	1.8	1.5	1.5	—	1.8
Silty sand	2.0	1.7	1.4	1.3	6.0	2.4
Gravel, loose	1.5	1.4	1.2	1.1	—	1.7
Sandy silt-clay	1.3	1.2	1.0	1.0	4.0	2.0
Light clay	.9	.8	.7	.7	1.9	1.7
Dry clay	.6	.6	.5	.5	1.4	1.7
Wet clay	.5	.5	.4	.4	1.2	1.2
Hardpan	.4	.4	.4	.4	1.4	1.7

Table LXXI. Horizontal and vertical curves.

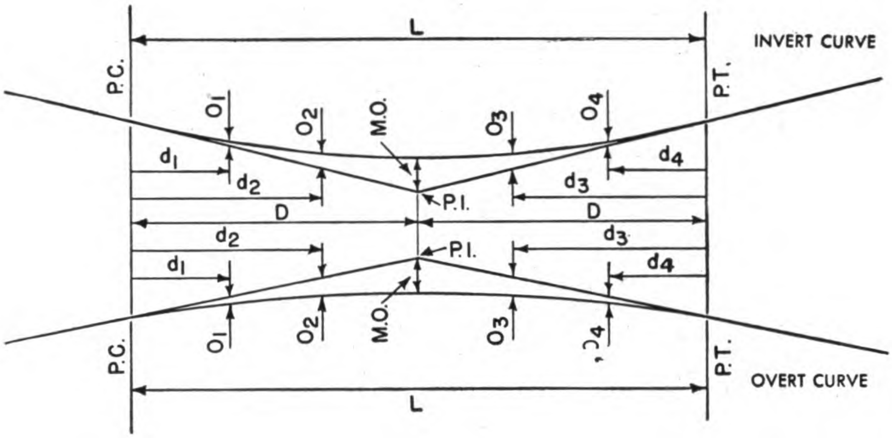
HORIZONTAL CURVES



P.C. – BEGINNING OF CURVE
P.T. – END OF CURVE
P.I. – POINT OF INTERSECTION OF TANGENTS
I. – INTERSECTION ANGLE: ANGLE OF DEFLECTION BETWEEN TANGENTS, (Δ)
D. – DEGREE OF CURVATURE: ANGLE AT THE CENTER SUBTENDED BY AN ARC OF 100 FEET
T. – DISTANCE FROM P.I. TO P.C. OR P.T. IS TANGENT DISTANCE
LONG CHORD – STRAIGHT LINE CONNECTING P.C. TO P.T.
L. – LENGTH MEASURED ALONG THE CURVE FROM THE P.C.
R. – RADIUS OF CURVATURE

THIS CHART IS FOR USE IN LAY-OUT OF HORIZONTAL CURVES WITHOUT AN INSTRUMENT, AND IS BASED ON A FIXED CHORD LENGTH OF 107 FEET.

VERTICAL CURVES



P.C. = BEGINNING OF CURVE

P.I. = POINT OF INTERSECTION OF GRADE TANGENTS

P.T. = END OF CURVE

L. = LENGTH OF CURVE (HORIZONTAL DISTANCE) MEASURED IN STATIONS (1 STATION = 100 FT.)

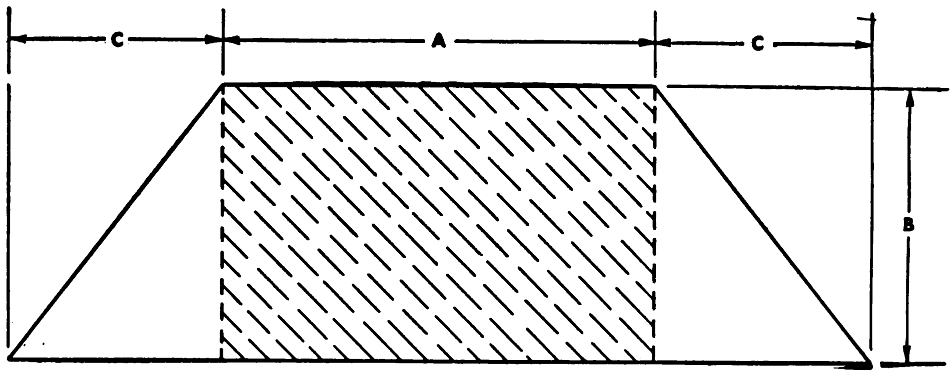
D. = $\frac{L}{2}$ = DISTANCE FROM P.C. OR P.T. TO THE P.I.
d_1, d_2, d_3, d_4 . . . ANY DISTANCE MEASURED **FROM** THE P.C. OR P.T. **TOWARD** THE P.I.

M.O. = MIDDLE ORDINATE = ⅛th THE ALGEBRAIC DIFFERENCE OF THE INTERSECTING GRADES MULTIPLIED BY THE LENGTH OF THE CURVE IN STATIONS. O_1, O_2, O_3, O_4 . . . ANY ORDINATE OTHER THAN THE MIDDLE ORDINATE, $O = \frac{d^2}{D^2} \times$ M.O.

THE ORDINATE IS THE VERTICAL DISTANCE FROM THE GRADE TANGENT TO THE CURVE.
THE ORDINATE IS ADDED TO THE TANGENT ELEVATION ON INVERT CURVES AND IS SUBTRACTED ON OVERT CURVES.

THIS CHART IS FOR USE IN DESIGN AND LAY-OUT OF VERTICAL CURVES.
LENGTH OF CURVES IS DETERMINED AS BY CRITERIA IN FIGURE 16.

Table LXXII. How to calculate cubic content of windrows.



TO CALCULATE CROSS-SECTIONAL AREA AND VOLUME IN A WINDROW:

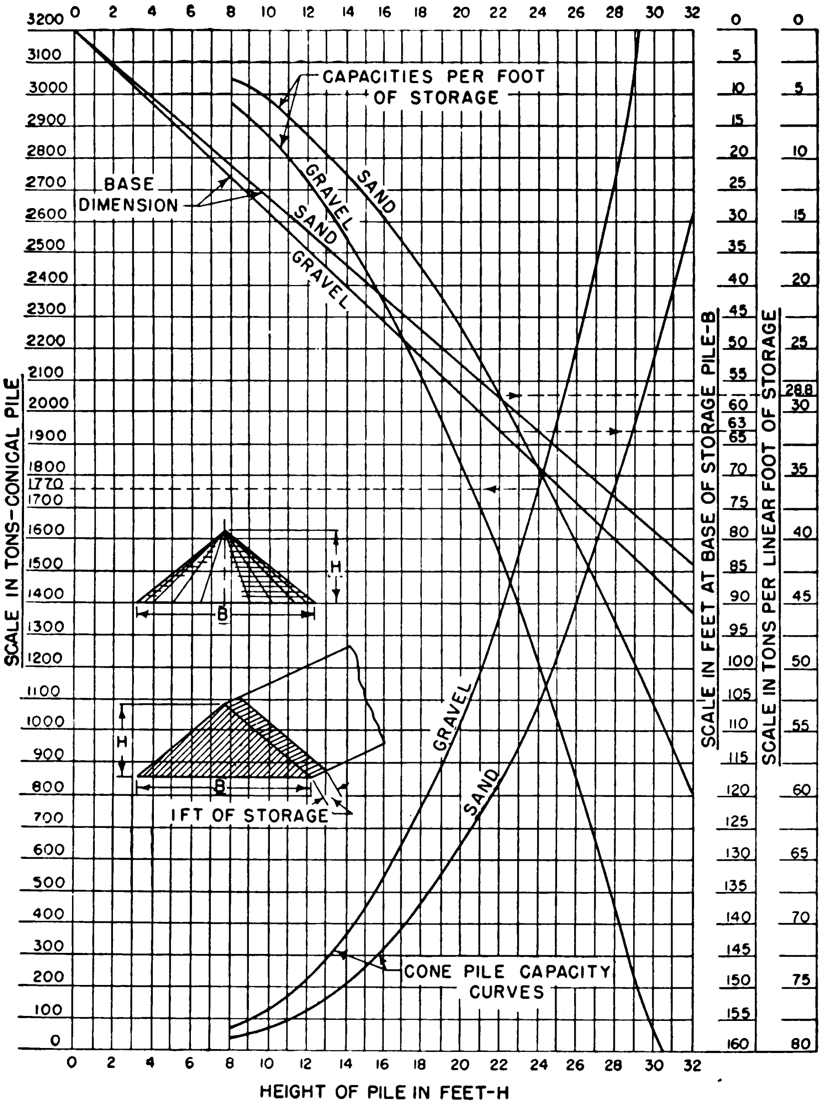
STEPS:

1. TAKE MEASUREMENT A, B, AND C.
2. A x B = AREA OF RECTANGULAR CENTER PART.
3. C x B = AREA OF BOTH TRIANGULAR SIDE PARTS.
4. (A x B) + (C x B) = TOTAL CROSS-SECTIONAL AREA OF WINDROW.
5. VOLUME IN CU. FT. OF A WINDROW IS OBTAINED BY MULTIPLYING CROSS-SECTIONAL AREA IN SQ. FT. BY LENGTH IN FT.

EXAMPLE:

1. BY MEASUREMENT A = 2 FT., B = 2 FT., C = 1 FT.
2. A x B = 2 x 2 = 4 SQ. FT.
3. C x B = 1 x 2 = 2 SQ. FT.
4. (A x B) + (C x B) = 4 + 2 = 6 SQ. FT. CROSS-SECTIONAL AREA.
5. THIS WINDROW CONTAINS 6 CU. FT. OF VOLUME FOR EACH FOOT OF LENGTH. IF THE WINDROW IS 1,200 FT. LONG, THE VOLUME IS 6 x 1,200 = 7,200 CU. FT.

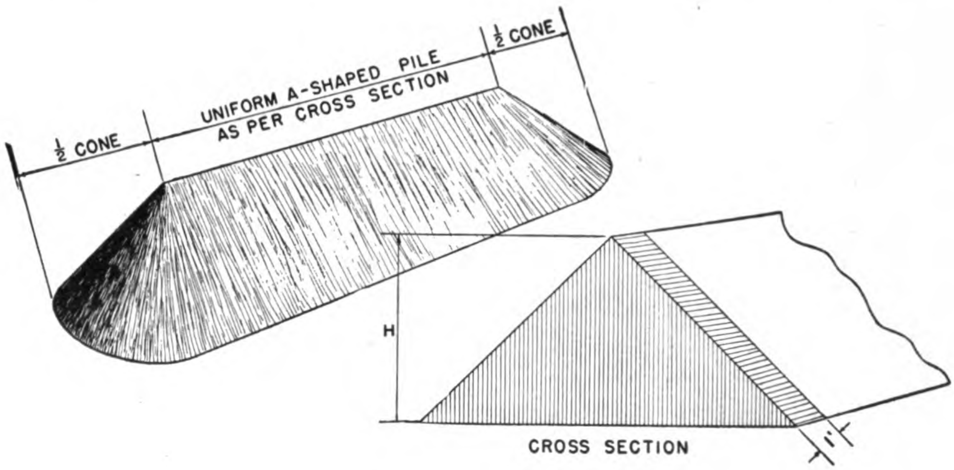
Table LXXIII. Storage-capacity curves.



EXPLANATION

a. Storage capacity of a conical pile.—Enter the chart on the horizontal line at the bottom and mark off the height of the pile in feet. Then proceed upward vertically to the point where the proper curve intersects this vertical line. Proceed horizontally from this point of intersection to the column at the left and read capacity in tons. For example, a 24-foot-high conical pile of gravel will hold 1,770 tons. (See arrow and dotted line on chart.)

b. Storage capacity of triangular pile. The two ends form one conical pile. The capacity of this can be determined as in *a* above. The intermediate pile can be figured from the "capacities per foot of storage" curves on the chart. Mark off the height of the pile in feet along the horizontal line at the top of the chart. Then, proceed vertically downward from this point to intersect a downward curving line (group of 2 curves marked "capacities per foot of storage") for the proper material. From this point of intersection, proceed horizontally to the last column at the right and read the number of tons per linear foot of storage. For example, a pile of sand 22 feet high will have 28.8 tons per foot of storage. (See arrow and dotted line on chart.) This answer,

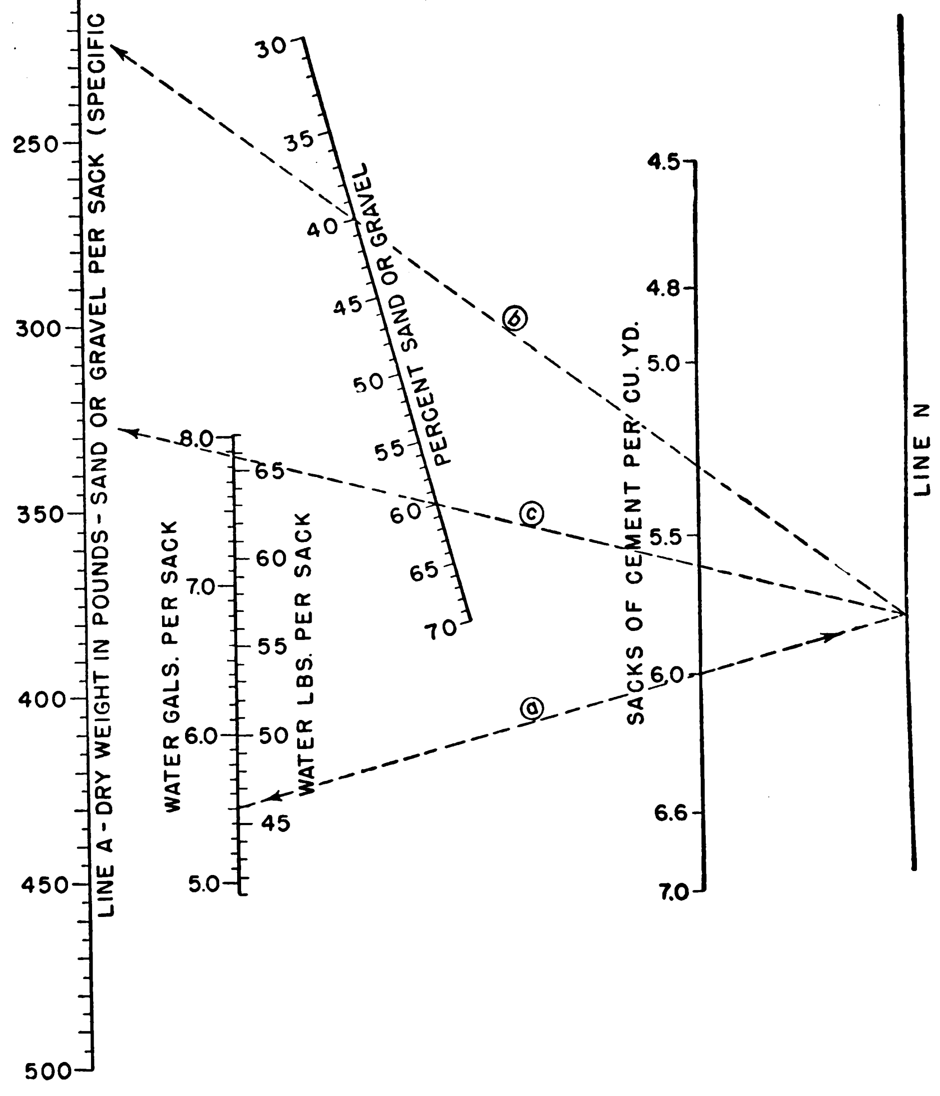


multiplied by the number of linear feet in the intermediate section of the pile, will be the total weight of the material in this section. If the weight of the material in the conical section is added to that for the intermediate section, the result will be the capacity of the entire pile.

c. Computing base dimension. The third set of curves on the chart are the "base dimension" curves. By their use it is possible to find the width of the base of a pile if its height is known. To use them enter the chart from the point corresponding to the number of feet in the height of the pile. Then, move vertically upward on this line to intersect the proper "base dimension" line. Next, move horizontally from the point of intersection to the first column at the right and read the width in feet of the base of the pile. For example, a pile of gravel 22 feet high will extend over a base area 63 feet wide. If it is a conical pile, 63 feet is the diameter of the circular area at its base. (See arrow and dotted line on chart.)

Table LXXIV. Concrete mixes.

WEIGHT CORRECTION FACTORS	
SP. GRAV.	FACTOR
2.90	1.09
2.85	1.07
2.80	1.06
2.75	1.04
2.70	1.02
2.65	1.00
2.60	0.98
2.55	0.96
2.50	0.94
2.45	0.92
2.40	0.90



EXPLANATION

The chart is used for rapidly proportioning and checking concrete mixes. For example, a mix is to be prepared using six sacks of cement per cubic yard of concrete and having a water-cement ratio of 5.5 gallons per sack. Fine aggregate is sand with a specific gravity of 2.60. Coarse aggregate is gravel with a specific gravity of 2.70. A mix using 40 percent sand and 60 percent gravel is selected for trial. Weight proportions for this trial mix are found as follows:

a. Place a straightedge at 6 sacks per cubic yard and at 5.5 gallons per sack and project a line to intersect line N.

b. Place a straightedge at the intersection on line N and at 40 percent for sand and project to intersect line A, in this case 218 pounds sand.

c. Place a straightedge at the same intersection on line N and at 60 percent for gravel and project to intersect line A, in this case 325 pounds gravel.

d. The weights of sand and gravel are corrected for specific gravity by multiplying by the "weight correction factor" for the respective specific gravities as follows:

$$\text{Sand} = 218 \times 0.98 = 214 \text{ pounds}$$

$$\text{Gravel} = 325 \times 1.02 = 332 \text{ pounds}$$

e. The proportions for the trial mix per sack of cement are—

5.5 gallons water: 1 sack (94 pounds) cement: 214 pounds sand; 332 pounds gravel.

f. The proportions in a batch using four sacks of cement, for example, are obtained by multiplying by 4:

22 gallons water: 4 sacks cement: 856 pounds sand; 1,328 pounds gravel.

A few trial batches are prepared using these proportions. Subsequent adjustments are made as needed until a satisfactory mix is obtained by changing the percentages of sand and gravel and recomputing their weights as above.

Table LXXV. Proportions, batch quantities, and unit quantities for concrete mixes.[1]

Maximum size of coarse aggregate	Water-cement ratio (U. S. gal. per sack)	Slump (inches)	Proportions by dry weight	Proportions by volume, dry-compacted	Materials for 1 batch in 14-cu.-ft. mixer, assuming average damp materials.[2]				Yield (cu. ft. of concrete per 1-sack batch)	Unit quantities of materials for 1 cubic yard of concrete[3]				
					Water (U. S. gal.)	Cement (94-lb. sacks)	Fine aggregate (cu. ft.) (damp-loose)	Coarse aggregate (cu. ft.) (damp-loose)		Cement (sacks of 94-lbs. each)	Weight (damp) Fine aggregate (tons)	Weight (damp) Coarse aggregate (tons)	Volume (damp-loose) Fine aggregate (cu. yd.)	Volume (damp-loose) Coarse aggregate (cu. yd.)
1 inch	5	½ to 1	1 2.0 3.1	1 1.7 2.8	9.7	3	6.1	8.9	4.07	6.64	0.65	0.99	0.51	0.73
		3 to 4	1 1.7 2.5	1 1.5 2.2	14.1	4	7.2	9.3	3.56	7.59	0.63	0.91	0.49	0.67
		5 to 7	1 1.4 2.0	1 1.2 1.8	15.2	4	5.7	7.6	3.11	8.68	0.60	0.83	0.47	0.61
	5½	½ to 1	1 2.2 3.4	1 1.9 3.0	10.7	3	6.9	9.5	4.40	6.14	0.66	1.00	0.51	0.73
		3 to 4	1 1.9 2.9	1 1.6 2.6	11.5	3	5.8	8.3	3.95	6.83	0.64	0.95	0.50	0.70
		5 to 7	1 1.6 2.3	1 1.4 2.1	16.4	4	6.8	8.9	3.50	7.71	0.60	0.85	0.47	0.62
	6	½ to 1	1 2.5 3.8	1 2.2 3.4	11.4	3	7.9	10.8	4.92	5.48	0.67	1.00	0.52	0.73
		3 to 4	1 2.2 3.4	1 1.9 3.0	12.2	3	6.9	9.6	4.47	6.03	0.65	0.98	0.51	0.72
		5 to 7	1 1.9 2.8	1 1.6 2.5	13.1	3	5.8	8.0	3.95	6.83	0.64	0.92	0.50	0.67
	6½	½ to 1	1 2.8 4.1	1 2.4 3.7	8.1	2	5.8	7.9	5.32	5.07	0.70	1.00	0.54	0.73
		3 to 4	1 2.5 3.7	1 2.1 3.3	13.1	3	7.6	10.5	4.86	5.55	0.68	0.98	0.53	0.72
		5 to 7	1 2.2 3.3	1 1.9 3.0	13.7	3	6.9	9.6	4.54	5.95	0.64	0.94	0.50	0.69
	7	½ to 1	1 3.0 4.3	1 2.6 3.9	8.8	2	6.3	8.3	5.63	4.80	0.70	1.00	0.54	0.73
		3 to 4	1 2.7 4.0	1 2.3 3.6*	9.3*	2*	5.5*	7.6*	5.24	5.15‡	0.68‡	0.99‡	0.53‡	0.72‡
		5 to 7	1 2.4 3.6	1 2.1 3.2	14.7	3	7.6	10.2	4.86	5.55	0.65	0.96	0.51	0.70
	8	½ to 1	1 3.4 4.9	1 2.9 4.4†	10.2†	2†	7.0†	9.4†	6.29	4.30	0.72	1.01	0.56	0.74
		3 to 4	1 3.1 4.7	1 2.7 4.2	10.5	2	6.5	8.5	6.04	4.47	0.68	1.01	0.53	0.74
		5 to 7	1 2.8 4.4	1 2.4 3.9	11.0	2	5.8	8.3	5.64	4.79	0.66	1.01	0.51	0.74

Table LXXV. Proportions, batch quantities, and unit quantities for concrete mixes.[1]*—Continued.*

Maximum size of coarse aggregate	Water-cement ratio (U. S. gal. per sack)	Slump (inches)	Proportions by dry weight	Proportions by volume, dry-compacted	Materials for 1 batch in 14-cu.-ft. mixer, assuming average damp materials.[2] Water (U. S. gal.)	Cement (94-lb. sacks)	Fine aggregate (cu. ft.) (damp-loose)	Coarse aggregate (cu. ft.) (damp-loose)	Yield (cu. ft. of concrete per 1-sack batch)	Unit quantities of materials for 1 cubic yard of concrete[3] Cement (sacks of 94-lbs. each)	Weight (damp) Fine aggregate (tons)	Weight (damp) Coarse aggregate (tons)	Volume (damp-loose) Fine aggregate (cu. yd.)	Volume (damp-loose) Coarse aggregate (cu. yd.)
2 inches	5	½ to 1	1 2.0 3.7	1 1.7 3.3	9.3	3	6.1	10.5	4.40	6.13	0.60	1.06	0.47	0.78
		3 to 4	1 1.7 3.0	1 1.5 2.7	10.2	3	5.4	8.6	3.88	6.96	0.58	1.00	0.45	0.73
		5 to 7	1 1.4 2.5	1 1.2 2.2	14.8	4	5.7	9.3	3.36	8.00	0.55	0.96	0.43	0.70
	5½	½ to 1	1 2.3 3.9	1 2.0 3.5	10.1	3	7.2	11.1	4.79	5.64	0.64	1.06	0.50	0.78
		3 to 4	1 2.0 3.4	1 1.7 3.0	11.1	3	6.1	9.6	4.30	6.28	0.61	1.03	0.47	0.76
		5 to 7	1 1.7 2.9	1 1.5 2.6	11.7	3	5.4	8.3	3.88	6.96	0.58	0.97	0.45	0.71
	6	½ to 1	1 2.6 4.4	1 2.2 3.9	7.3	2	5.3	8.3	5.24	5.15	0.65	1.06	0.51	0.78
		3 to 4	1 2.2 3.8	1 1.9 3.4	11.9	3	6.9	10.8	4.73	5.70	0.62	1.04	0.48	0.76
		5 to 7	1 2.0 3.4	1 1.7 3.0	12.6	3	6.1	9.6	4.34	6.22	0.61	1.01	0.47	0.74
	6½	½ to 1	1 2.8 4.7	1 2.4 4.2	7.9	2	5.8	8.9	5.64	4.80	0.66	1.07	0.51	0.79
		3 to 4	1 2.5 4.2	1 2.1 3.8	8.5	2	5.1	8.1	5.18	5.21	0.64	1.05	0.50	0.77
		5 to 7	1 2.2 3.8	1 1.9 3.4	13.4	3	6.9	10.8	4.80	5.62	0.61	1.03	0.47	0.76
	7	½ to 1	1 3.0 5.0	1 2.6 4.5	8.5	2	6.3	9.5	6.03	4.48	0.66	1.07	0.51	0.79
		3 to 4	1 2.7 4.5	1 2.3 4.0	9.1	2	5.5	8.5	5.51	4.90	0.64	1.05	0.50	0.77
		5 to 7	1 2.4 4.1	1 2.1 3.7	9.5	2	5.1	7.9	5.18	5.21	0.61	1.03	0.47	0.76
	8	½ to 1	1 3.4 5.5	1 2.9 4.9	9.9	2	7.0	10.4	6.62	4.07	0.68	1.07	0.53	0.79
		3 to 4	1 3.1 5.1	1 2.7 4.6	10.3	2	6.5	9.8	6.29	4.30	0.65	1.05	0.51	0.77
		5 to 7	1 2.8 4.6	1 2.4 4.1	10.9	2	5.8	8.7	5.77	4.68	0.64	1.03	0.50	0.76

[1] Proportions in table are computed using average values. They are intended as a guide for first trial mix. Aggregate proportions should be adjusted thereafter to give the desired workability (slump) without changing the water-cement ratio.

* *Example:* A two-sack batch using 1-inch maximum size aggregate, water-cement ratio 7 gallons per sack, slump 3 to 4 inches, and dry-compacted volumetric proportions of 1:2.3:3.6 is selected for trial. It turns out to be too wet (large slump) and appears to be oversanded. Investigation shows moisture content of aggregate about as shown in table LXXVI: 4 percent and 2 percent by weight respectively in fine and coarse aggregates.

To adjust this mix, first increase amount of coarse aggregate with a corresponding decrease in added water, thus economizing on cement and tending to correct oversanded condition. Batch quantities from table are:

Water .... 9.3 gallons
Cement .... 2.0 sacks
Fine aggregate .... 5.5 cu. ft. (damp-loose)
Coarse aggregate .... 7.6 cu. ft. (damp-loose)

Suppose coarse aggregate for second trial is increased 0.4 from 7.6 to 8.0 cubic feet (damp-loose). Adding 0.4 cubic feet coarse aggregate that carries ¼ gallon free water per cubic foot (table LXXVI) introduces ¼ × 0.4, or 0.1 gallon extra water. Adjusted batch quantities for second trial then are.

Water (9.3—0.1) .... 9.2 gallons
Cement .... 2.0 sacks
Fine aggregate .... 5.5 cu. ft. (damp-loose)
Coarse aggregate .... 8.0 cu. ft. (damp-loose)

[2] Batch quantities based on following assumptions: moderately wet sand carrying ½ gallon of free moisture per cubic foot with damp-loose volume 1.20 times dry-compacted volume; moist gravel carrying ¼ gallon of free moisture per cubic foot with damp-loose volume 1.06 times dry-compacted volume. Water quantities have been adjusted for moisture carried by aggregate. Amount shown is to be added at the mixer.

† *Example:* Assume a mix with water-cement ratio of 8.0 and dry-compacted proportions 1 to 2.9 to 4.4. The damp-loose proportions are 1 to 2.9 × 1.20 to 4.4 × 1.06 = 1 to 3.5 to 4.7. Free moisture carried by the aggregate is ½ × 3.5 + ¼ × 4.7 = 2.9 gallons. The net water to be added at the mixer is 8.0 — 2.9 = 5.1 gallons. A two-sack batch of this mix would require:

2 × 5.1 = 10.2 gallons of water added at the mixer.
2 × 1 = 2 sacks of cement.
2 × 3.5 = 7.0 cubic feet of damp-loose sand.
2 × 4.7 = 9.4 cubic feet of damp-loose gravel.

Batch quantities for each mix are shown for whole numbers of sacks of cement to give a batch volume not greater than 14 cubic feet.

[3] Unit quantities based on following assumptions: moderately wet sand carrying 4 percent moisture by weight (½ gallon per cubic foot) with damp-loose volume 1.20 times dry-compacted volume; moist gravel carrying 2 percent moisture by weight (¼ gallon per cubic foot) with damp-loose volume 1.06 times dry-compacted volume.

To estimate quantities for a particular job, multiply unit quantities by the total volume in cubic yards of concrete to be placed, and add about 5 percent to cover unavoidable loss and waste.

‡ *Example:* 120 cubic yards of concrete are to be placed using a 1 to 2.3 to 3.6 mix (by dry-compacted volume), water-cement ratio 7 gallons per sack, and 1-inch maximum size aggregate. Estimate of quantities of materials needed with a 5 percent margin for unavoidable loss and waste is:

a. By volume:

Material	*Concrete to be placed*		*Allowance for waste*		*Unit quantity from table*	*Quantity needed*
Cement	120	×	1.05	×	5.15 =	649 sacks (162 barrels).
Fine aggregate (sand)	120	×	1.05	×	0.53 =	67 cubic yards (damp-loose).
Coarse aggregate (gravel)	120	×	1.05	×	0.72 =	91 cubic yards (damp-loose).
b. By weight:						
Cement	120	×	1.05	×	5.15 =	649 sacks at 94 pounds each = 61,000 pounds or 30.5 tons.
Fine aggregate (sand)	120	×	1.05	×	0.68 =	86 tons (damp).
Coarse aggregate (gravel)	120	×	1.05	×	0.99 =	125 tons (damp).

Table LXXVI. Approximate quantity of surface water carried by average concrete aggregates.

Aggregate	Gallons per cubic foot
Extremely wet sand	¾ to 1.
Moderately wet sand	About ½.
Moist sand	About ¼.
Moist gravel or crushed rock	Do.

NOTE. Specific determination of moisture is made by measuring the difference in weights of a **sample of damp aggregate** and the same sample surface-dry.

Table LXXVII. Wind rose.

STATION __________________ ELEVATION __ ANNUAL __________ PERIOD __________

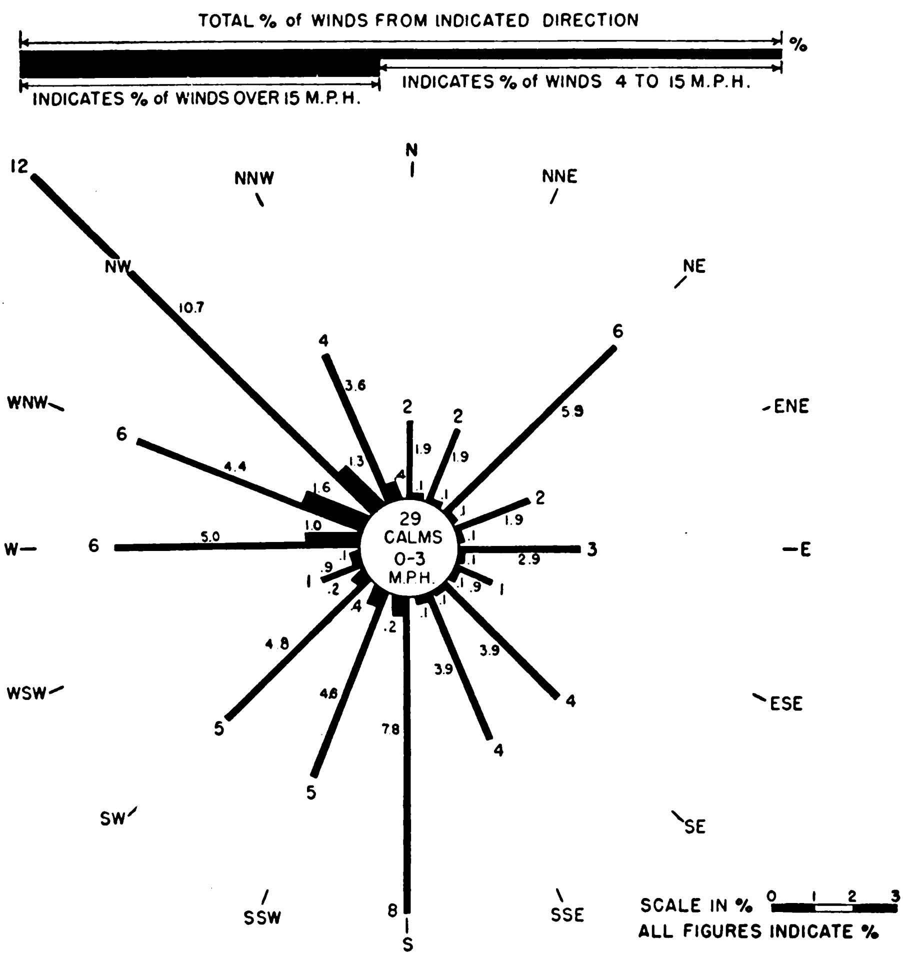
M.P.H. \ DIR	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL OBS	PERCENT
4-15	1835	1578	4307	1555	2113	1147	2973	3332	6155	3289	3372	806	3735	3456	8448	2533	50634	65
16-31	94	65	98	49	20	6	17	33	178	256	170	103	742	1342	1545	316	5034	6
32-47	1		2	1				1			6	4	36	57	57	3	168	#
OVER 47											1		1				2	#
CALM 0-3																	22860	29
TOTAL O.B.S.	1930	1643	4407	1605	2133	1153	2990	3366	6333	3545	3549	913	4514	4855	10050	2852	78698	
29	2	2	6	2	3	1	4	4	8	5	5	1	6	6	12	4		100

\# INDICATES LESS THAN ½ OF 1%

MAXIMUM WINDS (M.P.H.)

STATION __________________ ELEVATION ______ YEARS OF RECORD __________

YEAR \ MONTH	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	MAXIMUM
1930			WNW 40 20 HR	WNW 46 12 HR	NW 40 20 HR						NW 42 22 HR	NW A 42 19 HR A	46
1931	W 34 6 HR	NW 37 13 HR	W 34 13 HR	NW 46 17 HR	WNW 36 13 HR		SW 52 15 HR	W 35 17 HR			SW 38 4 HR	W 40 16 HR	52
1932	W A 36	W 39	W 50	W 32									50
1933		WNW A 40 7 HR A	WNW 33 14 HR					ENE 36 17 HR			W 40 1 HR	WNW 38 14 HR	40
1934	NW A 40 1 HR A	WNW 38 13 HR	WNW 38 18 HR			W 42 23 HR				WNW 44 15 HR		NW 34 14 HR	44
1935	NW 43 15 HR		NW 35 16 HR	WSW 35 22 HR	W 38 11 HR							WNW 36 19 HR	43
1936	NW 40 1 HR	WNW 34 15 HR	WNW 39 14 HR	W 32 14 HR	NW 39 16 HR	WNW 35 16 HR					WNW 43 16 HR		43
1937		WNW 34 23 HR		WNW 32 17 HR								W 33 11 HR	34
1938	W 38	W 35	W 38	WSW 33								WNW 33	38
MAXIMUM	43	40	50	46	40	42	52	36		44	43	42	52.



AIR BASE LOCATION

SURFACE WIND VELOCITY OVER A PERIOD OF 9 YEARS. U.S. WEATHER BUREAU (AIR BASE) (CITY) STATION

REMARKS: The above information covers a period ending with 1938. CHECK WHICH

Table LXXVIII. Engineer pump types and capacities.

Use	Mount	Power	Type	Capacity (gpm)	Pump speed (rpm)	Discharge (inches)	Head (feet)
Asphalt	Trailer-mounted	Gasoline engine	*Organic* Positive-displacement with spray bar	350	350		
Water	Base-mounted	Gasoline engine	Centrifugal	166	1, 600	2	25
Sump	None	Compressor (55–90 cfm)	Pneumatic	175		3	25
Water	Steel-wheel-mounted	Gasoline engine	Diaphragm	100	1, 600	4	10-foot suction-head
Water	Trailer-mounted	Gasoline engine	Water-distributor with spray bar	[1]400			103.5
				[2]350			46
Water	Base-mounted	Gasoline engine	*Stock pile* Centrifugal	55	2, 275	2	50
Water	Base-mounted	Gasoline engine	Centrifugal	60	2, 000	2	125
Water	Base-mounted	Gasoline engine	Centrifugal	125	1, 860	1½	300
Water	Base-mounted	Gasoline engine	Centrifugal	200	2, 250	4	350
Water	Base-mounted	Gasoline engine	Centrifugal	480	2, 250	4	300
Water	Base-mounted	Gasoline engine	Centrifugal	500	2, 200	4	20
Gasoline	Base-mounted	Gasoline engine	Centrifugal	175		4	1, 453 4-inch suction-head
Gasoline	Base-mounted	Gasoline engine	Centrifugal	1, 000		6	300

Table LXXVIII. Engineer pump types and capacities.—Continued.

Deep well		Gasoline engine	Helical-rotor	30	1, 750	4	250
Deep well		Gasoline engine	Helical-rotor	60	2, 100	4	250
Deep well		Gasoline engine	Turbine	200	1, 800		200
Mudjack	Trailer-mounted	Gasoline engine		5 cubic yards, /hour			

[1] Without spray-bar attachment.
[2] With spray-bar attachment.

Table LXXIX. Cable requirements.

1	2	3		5				6	7
				Length in feet					
List of equipment	Model	Attachments	Use	See notes column 7	Diameter			Average total working life*	Notes
					½ in. (6 x 19)	9/16 in. (6 x 19)	⅝ in (6 x 19)		
Crane, truck-mounted, with pile driver. ⅜-yd. dragline and trail.	E	Winch		250					⅝ in. (6 x 37)
		Crane	Boom	190				12 months	
			Hoist		110			2 months	
			Tagline	100				3 months	⅜ in. (6 x 19)
		Dragline	Boom		145			6 months	
			Drag		50			120 hours	
			Hoist		80			200 hours	
		Shovel	Boom		105			12 months	
			Haul back		30			2 months	
			Hoist		80			3 months	
		Pile driver	Boom	250					½ in. (6 x 37)
			Hoist	190					
		Clamshell	Hoist	80				200 hours	
			Closing	110				150 hours	
Crane, tractor-operated	M–20		Boom		245			4 months	
			Hoist		215			2 months	
Ditching machine, crawler-mounted	44C		Scraper hoist	12.5				12 months	⅜-in. (6 x 42) Crucible tiller Hemp center
					82			6 months	
Rooter	H3		Teeth control		85			4 months	

Table LXXIX. *Cable requirements.—Continued.*

Scraper	L. S.		Tail gate forward		120			2 months	
			Tail gate to traveling sheaves				37	2 months	
			Apron to traveling sheaves				11	8 months	
			Lift cable		85			4 months	
			Spring cable		14			12 months	
			Spiral cable to tail gate		11			12 months	
			Replacement		180			6 months	
Shovel, gasoline-engine, ½-cubic-yard	Bucyrus	Crane	Suspension		270			12 months	
			Hoist			120		2 months	
		Clamshell	Tagline	90				3 months	5/16-in. improved plow steel, hemp center
			Holding			80		200 hours	
			Closing			110		150 hours	
		Dragline	Hoist			85		200 hours	
			Drag				45	120 hours	
		Shovel	Suspension		110			12 months	
			Hoist			75		3 months	
			Haul back			20		2 months	
			Crowd			44		2 months	
			Dipper trip	35				2 months	5/16-in. improved plow steel, hemp center
Shovel, gasoline-engine, ½-cubic-yard	Osgood 200	Crane	Boom hoist		170			6 months	
			Hoist		118			2 months	
		Clamshell	Tagline	60				3 months	¼-in. (6 x 19)
			Holding		87			200 hours	
			Closing		115			150 hours	
		Dragline	Hoist		87			100 hours	
			Pulling				50	60 hours	
		Shovel	Boom hoist		100			6 months	
			Hoist		60			1 month	
			Trip line	50				2 months	¼-in. (6 x 19)

Table LXXIX. Cable requirements.—Continued.

1	2	3	4	5				6	7
				Length in feet					
				See notes column 7	Diameter				
List of equipment	Model	Attachments	Use		½ in. (6 x 19)	9/16 in. (6 x 19)	⅝ in. (6 x 19)	Average total working life*	Notes
Tractor, 80-dbhp	D–7	Angledozer WCK–7			65			2 months	
Truck, ¾-ton	Dodge WC–57	Winch			300				Hemp center
Truck, 1½-ton	G–7106	Winch			300				Hemp center
Truck, 2½-ton	CCKW352	Winch					300		Hemp center
Truck, 4-ton	968	Winch					300		Hemp center
Truck, 6-ton	50FD6	Winch					300		Hemp center

* Working life of cable depends on many conditions and factors. Average life given intended as general approximate guide.
NOTE. Specification of cable (unless otherwise noted): improved plow steel, preformed, long lay, independent wire rope center.

APPENDIX VI

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Engineer Troops .... FM 5–5
Operations of Engineer Field Units........................ FM 5–6
Construction and Routes of Communications.................. FM 5–10
Field Fortifications .... FM 5–15
Camouflage, Basic Principles.................and supplements FM 5–20
Explosives and Demolitions............................... FM 5–25
Land Mines and Booby Traps............................... FM 5–31
Military Training .... FM 21–5
List of Publications for Training......................... FM 21–6
List of Training Films, Film Strips and Film Bulletins......... FM 21–7
Military Training Aids................................... FM 21–8
Military Sanitation and First Aid......................... FM 21–10
Elementary Map and Aerial Photograph Reading.............. FM 21–25
Defense Against Chemical Attack.......................... FM 21–40
Motor Transport .... FM 25–10
Recognition Pictorial Manual............................. FM 30–30
Landing Operations on Hostile Shores...................... FM 31–5
Field Service Regulations—Larger Units.....................FM 100–15
Organization, Technical, and Logistical Data.................FM 101–10

b. Technical Manuals.

Electrical Fundamentals .... TM 1–455
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Carpentry .... TM 5–226
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Fire Protection by Troop Organizations in Theater of Operations	TM 5–315
Military Pipe Line Systems	TM 5–350
Bituminous Distributor,	
Model MX	TM 5–519–4 and 519–6
Export	(Tentative) TM 5–9711
Storage	(Tentative) TM 5–9715
Water Transportation, Stevedoring and Stowing	TM 10–381
Army Instruction	TM 21–250
Army Supply Manual	TM 38–205
Basic Maintenance Manual	TM 38–250

c. Maintenance Manuals and Parts Catalogs. Manuals covering operation, repair, and lubrication of each item of engineer equipment, and containing a parts list, are available from Engineer Field Maintenance Office, P. O. Box 1679, Columbus, Ohio.

d. Engineer Maintenance Circulars. EMC–2020 series. Technical data for Corps of Engineers equipment. Available from Engineer Field Maintenance Office, P. O. Box 1679, Columbus, Ohio.

2. TECHNICAL. a. *Engineering Manual,* Corps of Engineers.

b. *Specifications for Construction of Roads and Bridges,* FP–41, Public Roads Administration.

c. *Standard Specifications for Highway Materials and Methods of Sampling and Testing,* American Association of State Highway Officials, National Press Building, Washington, D. C.

3. TEXTBOOKS (available by purchase). **a.** *Engineering Properties of Soil,* by C. A. Hogentogler. McGraw-Hill, New York, N. Y.

b. *Highway Design and Construction,* by Bruce. International Textbook Co., Scranton, Pa.

c. *Highway Engineer's Handbook,* by Harger and Bonney. McGraw-Hill, New York, N. Y.

d. *Highway Materials,* by Bauer. McGraw-Hill, New York, N. Y.

4. TRADE ASSOCIATION PUBLICATIONS (available by request or purchase). **a. Cement Construction.** (1) *Design and Control of Concrete Mixtures.* Portland Cement Association, Chicago, Ill.

(2) *Soil-Cement Roads* (Construction Handbook) and *Soil-Cement Mixtures* (Laboratory Handbook). Portland Cement Association, Chicago, Ill.

(3) Manuals on design, construction, and inspection of concrete pavements for roads and airports.

b. Asphalt construction. (1) *Asphalt Pocket Reference for Highway Engineers.* The Asphalt Institute, 801 Second Ave., New York, N. Y., or 100 Bush St., San Francisco, Calif.
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(2) *Bulletins* on drainage may also be obtained from American Concrete Pipe Association, 33 W. Grand Ave., Chicago, Ill.
(3) *Handbook of Culvert and Drainage Practice.* Armco Drainage Products Association, Middletown, Ohio.

5. OTHER PUBLICATIONS (available by request). Bulletins on tar construction may be obtained directly from manufacturers of tar products, such as *The Barrett Road Book,* The Barrett Co., 40 Rector St., New York, N. Y., and *Tarmac Handbook,* The Koppers' Co., Pittsburgh, Pa.

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☆ U. S. GOVERNMENT PRINTING OFFICE : 1944